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Multi-Hazard Early Warning and Disaster Risks

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In memory of Prof. Samantha Hettiarachchi,
for his tireless commitment to the
development of disaster risk knowledge, and
taking science to practice

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Preface

During the time period in which this book was being written, countries around the world have been tackling the COVID-19 global pandemic. Never in human history have so many people recognised and started to understand the importance of disaster risk.

In the short term, countries have been dealing with rapidly rising infection rates and excess deaths associated with COVID-19. In the longer term, there will be a devastating legacy on health as vital resources have been diverted away from other essential health services and specialist treatments.

The economic impacts of the pandemic are also going to have a devastating impact on our attempts to alleviate poverty. In order to combat the spread of the infection, many governments have engineered a deliberate slowdown in the economy to manage the health risks. This approach has generally involved closing borders, introducing social distancing and quarantine measures, and prohibiting specific activities. Recent estimates suggest that the impact of this economic disruption due to the COVID-19 pandemic could cost 21 trillion US dollars.

As well as in these direct and indirect impacts, the COVID-19 pandemic has also brought to the forefront the concept of systemic risk and the need for a multi-hazard approach to disaster risk reduction and early warning.

Systemic risks are those of high complexity that are interconnected. Cascading impacts, of the type many countries and people have experienced during the pandemic, are often inadequately understood and rather unpredictable in terms of cause and effect. They are often transboundary in nature, challenging our decision-makers as they do not easily fit into existing international, national, or sub-national administrative or sectoral structures.

The pandemic has also exposed existing vulnerabilities, including weaknesses in existing healthcare and support structures, but also disproportionately affecting the poorest members of our communities. Underlying drivers of disaster risk have been exposed, including human rights, poverty, inequality, and global supply chains.

Having a common framework to cope with such complex disasters can make it easier for decision-makers and other actors, including people at risk, to understand the cascading effects and therefore where to prioritise in their efforts to prepare and mitigate for disaster risk.

The need for this multi-hazard approach is set out in The Sendai Framework for Disaster Risk Reduction 2015–2030 (Sendai Framework), which was signed in 2015 and became the first major agreement of the post-2015 development agenda. It provided the Member States with concrete actions to protect development gains from the risk of disaster.

The Sendai Framework works hand in hand with the other 2030 Agenda agreements, including The Paris Agreement on Climate Change, The Addis Ababa Action Agenda on Financing for Development, the New Urban Agenda, and ultimately the Sustainable Development Goals. It was endorsed by the UN General Assembly following the 2015 Third UN World Conference on Disaster Risk Reduction (WCDRR), and advocates for *The substantial reduction of disaster risk and losses in lives, livelihoods and health and in the economic, physical, social, cultural and environmental assets of persons, businesses, communities and countries.*

The Sendai Framework recognises that the state has the primary role to reduce disaster risk, but that responsibility should be shared with other stakeholders including local government, the private sector, and other stakeholders.

During the negotiations for the Sendai Framework, countries and partners highlighted the need to:

1. Continue to invest in, develop, maintain, and strengthen people-centred, end-to-end early warning systems;
2. Promote the application of simple and low-cost early warning equipment and facilities;
3. Broaden the dissemination channels for early warning information to facilitate early action.

Countries also called for the further development of and investment in effective, nationally compatible, and regional multi-hazard early warning mechanisms. To address these needs, global target (g) of the Sendai Framework was adopted, namely to "substantially increase the availability of and access to multi-hazard early warning systems and disaster risk information and assessments to the people by 2030".

Around the world, meteorological and hydrological services have developed and implemented multi-hazard early warning systems (MHEWS) for weather and climate-related hazards. A MHEWS has the ability to address several hazards and/or impacts of similar or different type in situations where hazardous events may occur alone, simultaneously, cascading or cumulatively over time, and taking into account the potential interrelated effects.

To be effective, a MHEWS should include the participation of different stakeholders and actively involve the people and communities at risk, in order to ensure that the system has an enabling environment, which incorporates the appropriate technology, regulatory and legal frameworks, adequate operational capacities, as well as to clearly defined roles and responsibilities for all participating agencies including communities.

There is now increasing recognition that efforts on MHEWS must expand to address a wider array of hazards, including biological such as epidemics and pandemics, as well as cascading impacts. A multi-hazard approach can be common for all hazards and is therefore more likely to become trusted so everyone can understand and use as a basic element of their efforts towards disaster risk reduction.

In reflecting upon these efforts, this book brings together a collection of empirical research, case studies, discussion, and insights on the need for and challenges associated with developing multi-hazard early warning systems, as well as wider perspectives on disaster risk reduction.

The chapters are primarily drawn from contributions to an international symposium on multi-hazard early warning and disaster risk reduction that was originally scheduled for March 2020, to be held in Colombo, Sri Lanka. The event was postponed due to the global pandemic, and instead held online, in December 2020. The event was jointly organised by:

- State Ministry of National Security, Home Affairs and Disaster Management, Sri Lanka
- Disaster Management Centre, Sri Lanka
- Global Disaster Resilience Centre, University of Huddersfield, UK
- University of Moratuwa, Sri Lanka
- Asian Disaster Preparedness Centre (ADPC), Thailand.

The organisers were supported by a wide range of national and international partners representing disaster-related actors from government, non-governmental organisations, universities, and research projects as follows:

- The International Oceanographic Commission of UNESCO (IOC-UNESCO), Intergovernmental Coordination Group for the Indian Ocean Tsunami Warning and Mitigation System (ICG/IOTWMS) ICG/IOTWMS WG 1 on Tsunami Risk, Community Awareness and Preparedness
- IOC-UNESCO IOTWMS, WG 1 on Tsunami Risk, Community Awareness and Preparedness
- United Nations Office for Disaster Risk Reduction (UNDRR)
- International Union for Conservation of Nature (IUCN), Sri Lanka
- Department of Meteorology, Sri Lanka
- Association of Disaster Risk Management Professionals in Sri Lanka (ADRiMP)
- University of Peradeniya, University of Colombo, University of Ruhuna, Sri Lanka
- REbuildinG AfteR Displacement (REGARD) project
- Capacity Building in Asia for Resilience EducaTion (CABARET) project on fostering regional cooperation for more effective multi-hazard early warning and increased disaster resilience among coastal communities
- Improving COVID-19 and pandemic preparedness and response through the downstream of multi-hazard early warning systems project
- Bandung Institute of Technology (ITB), Indonesia
- Regional Dialog of Asian Preparedness Partnership (APP)
- The United Nations World Food Programme
- The United Nations Development Programme (UNDP)

- The Japan International Cooperation Agency (JICA)
- ChildFund Sri Lanka.

Many of the chapters reflect the original venue for the symposium and provide contemporary insights into the challenges in Sri Lanka for developing and implementing a multi-hazard approach to early warning and wider efforts on disaster risk reduction.

Sri Lanka experienced devastating effects when there are inadequate early warning systems. The lack of a tsunami early warning system and poor preparedness of communities resulted in the death of over 30,000 people in Sri Lanka and the displacement of many more. Sri Lanka was not alone in these failings, as the Indian Ocean did not have the type of tsunami early warning system that had been operating in the Pacific since the 1960s. As a result, communities along the surrounding coasts of the Indian Ocean were severely affected, and the tsunamis killed an estimated 227,898 people in 14 countries. The direct results caused major disruptions to living conditions and commerce, particularly in Indonesia, Sri Lanka, India, and Thailand.

Following the disaster, the Intergovernmental Oceanographic Commission (IOC) of UNESCO was given the mandate to develop and implement the Indian Ocean Tsunami Warning and Mitigation System (IOTWMS). The Intergovernmental Coordination Group (ICG) for the IOTWMS was established as a primary subsidiary body of the IOC by its July 2005 Assembly (Resolution XXIII-12). Further mandates were given to UNESCO/IOC by the UN General Assembly through Resolutions 61/132 and 62/91.

After 8 years of international collaboration and development, facilitated and coordinated by UNESCO/IOC, the IOTWMS became fully operational on 31 March 2013 with Tsunami Service Providers (TSPs) established by Australia, India, and Indonesia.

An end-to-end tsunami warning system begins with the upstream rapid detection of a tsunami wave, including detection, verification, threat evaluation, and forecasting. It ends with a well-prepared community that is capable of responding appropriately to a warning, including delivery of public safety messages, risk assessment and management, initiating national countermeasures, and preparing and implementing standardised reactions.

As illustrated by the 2018 Sunda Strait and Central Sulawesi tsunami events in Indonesia, it is also vital to address the challenge of cascading hazards that pose a tsunami risk and the importance of linking tsunami early warning to a multi-hazard environment. Moving towards a multi-hazard environment is complex and poses many challenges, but can bring significant benefits in terms of efficiencies and also in recognising the links between hazards, such as cascading threats.

Reflecting the multiplicity of the challenges and the need for a diversity of scientific perspectives and methodological approaches, the book's 56 chapters address a range of important topics, many of them drawing upon experiences and results from Sri Lanka.

The chapters are spread across five broad themes. The opening nine chapters address the Sendai Framework and Sustainable Development Goals, including the importance of wider policy coherence. The need to draw synergies between climate change, disaster risk, and sustainable development is also reflected in many of the seventeen chapters that focus on disaster risk reduction and eight on disaster preparedness. Seventeen chapters focus more directly on the development of effective early warning systems, including better communications and need for multi-hazard approaches. The final five chapters address the need to integrate health into disaster risk reduction, including some early reflections on COVID-19 and the need to address epidemic and pandemic threats in preparedness planning.

As editors, it is our hope that this important collection of scientific results, discussion, and insights provides a useful point of reference that reflects upon our progress to date in tackling disaster risk in Sri Lanka, but also across the wider region and globally. We also hope it sets out some of the challenges and opportunities that lay ahead of us if stakeholders are to successfully develop a common framework that will help our communities to better prepare for and tackle complex, multi-hazard threats.

Huddersfield, UK
December 2020

Prof. Dilanthi Amaratunga
Prof. Richard Haigh
Dr. Nuwan Dias

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About the Editors

Prof. Dilanthi Amaratunga holds the chair in Disaster Risk Management at the University of Huddersfield, UK. She is a leading international expert in disaster resilience with an extensive academic career that has a strong commitment to encouraging colleagues and students to fulfil their full potential. She provides expert advice on disaster resilience to national and local governments and international agencies including the United Nations Office for Disaster Risk Reduction. She is engaged in many significant research engagements around the world, in partnership with key academic and other organisational stakeholders. To date, she has produced over 400 publications, refereed papers and reports, and has made over 100 keynote speeches in around 30 countries. Among many leadership roles, she is the joint chief editor of the International Journal of Disaster Resilience in the Built Environment and the chair of the International Conference on Building Resilience (ICBR) series, which she co-created. She is a member of the European Commission and UNDRR's European Science and Technology Advisory Group representing the UK, a member of the Steering Committee of the UNISDR "Making Cities Resilient" Campaign, and a Steering Committee member of the Frontiers of Development programme, a Collaborative Programme of The Royal Academy of Engineering, The Academy of Medical Sciences, The British Academy and The Royal Society. She is a fellow of the Royal Institution of Chartered Surveyors (RICS), a fellow of The Royal Geographical Society, a fellow, and a chartered manager of the Chartered Management Institute, UK. She can be contacted on: d.amaratunga@hud.ac.uk.

Prof. Richard Haigh is a professor of Disaster Resilience and a co-director of the University of Huddersfield's Global Disaster Resilience Centre in the UK. His research interests include multi-hazard early warning, disaster risk governance and resilience in the built environment. He is the editor-in-chief of the International Journal of Disaster Resilience in the Built Environment and the co-chair of the International Conferences on Building Resilience, which started in 2008. He is an expert member of Working Group 1 of Intergovernmental Coordination Group on the Indian Ocean Tsunami Warning and Mitigation System (ICG/IOTWMS). He and his team won the Newton Prize for Indonesia, celebrating the best research innovation partnership for the project Mainstreaming Integrated Disaster Risk Reduction and Climate

Change Adaption Strategies into Coastal Urban Agglomeration Policy. He has led and successfully delivered research grants funded by the UK Natural Environment Research Council, the European Commission's Horizon 2020, Erasmus+, Framework Seven Programme, Lifelong Learning, Asia Link and European Social Fund, the UK Newton Fund, the UK Foreign and Commonwealth Office, British Council and UK Parliamentary Under Secretary of State for Business, Energy and Industrial Strategy. Many of these projects were carried out in close collaboration with government, non-government organisations, and industry partners. He has published widely, including an edited book by Wiley Blackwell, fifteen edited chapters and forty-five peer-reviewed journal articles, the majority of which are in ISI or SCOPUS indexed journals. He has delivered over 80 invited speeches and keynote presentations for audiences in twenty-five countries across North America, South America, Europe, Asia, Africa, and Australasia.

Dr. Nuwan Dias is a research fellow in Disaster Resilience at the Global Disaster Resilience Centre, University of Huddersfield, UK. His research interests include multi-hazard early warning, integration of climate change adaptation to disaster risk reduction, and resilience in urban planning and design. He has delivered over 10 invited speeches and keynote presentations for audiences in Europe, South Asia, and South East Asia. He has chaired over 20 sessions in international conferences and presented his research work in more than 30 international audiences. Further, Nuwan has published two edited chapters and 12 peer-reviewed journal articles. He is involved in developing research impact case studies for the UK Research Excellence Framework (REF2021) under the Unit of Assessment 13, Architecture, Built Environment and Planning for the University of Huddersfield. He has worked in many international research projects funded by the European Commission's Horizon 2020, Erasmus+, Lifelong Learning, and the Global Challenges Research Fund in different capacities. In his different roles, he has worked with multi-stakeholders including government, non-government organisations, and industry partners. He earned his Ph.D. in Urban Design from the University of Huddersfield, UK, his master's degree from the University of Salford, UK, and the undergraduate degree from the University of Moratuwa, Sri Lanka. Further, he is a fellow member of the Higher Education Academy of the UK. He can be contacted on: n.dias@hud.ac.uk.

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Life Two years After Relocation: Status Quo of Natural Hazard Induced Displacement and Relocation in Kegalle, Sri Lanka

Nishara Fernando, Dilanthi Amaratunga, Richard Haigh, Belinda Wise, Jude Prasanna, and Naduni Jayasinghe

Abstract High impact disasters have been occurring frequently since 2011 in Sri Lanka, affecting more than 1 million people annually (Sri Lanka Rapid Post Disaster Needs Assessment Floods and Landslides, 2017). Torrential rains which resulted in severe flooding and landslides in 2016 affected almost 20 of the 25 districts. Following the landslides, the Kegalle District Secretariat undertook the responsibility of resettling families that resided in high risk zones and those whose houses were damaged. These were implemented as a disaster risk reduction strategy with the technical assistance of the National Building Research Organization (NBRO). Houses were built by using 2 approaches: (1) Donor driven and (2) Owner driven. Under the owner driven approach, two housing options were made available to people, namely: (1) Owner Driven at Government Relocation Sites [GRS] (2) Owner Driven at Individual Relocation Sites [IRS]. This paper explores the status of relocated families two years after relocation based on five indicators, namely, the impact on savings, physical housing conditions and satisfaction, social capital, access to common services, and possession of documents to prove ownership. Interviews were conducted with a randomly selected sample of 435 household heads of each housing type 129 Donor Built households (Under the Donor Driven approach, houses were constructed by donors with material and labour supply.), 190 GRS (Under the GRS approach, the government allocated a plot of minimum 10 perches of land for house construction. Further, beneficiaries were granted LKR. 1.2 million for house construction in four (04) installments based on the stage of completion.) and 116 IRS (Under the IRS approach, beneficiaries were granted a lump sum of LKR. 0.4 million to

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purchase land for house construction in addition to LKR. 1.2 million granted for house construction.) households in the Kegalle District in Sri Lanka. The findings reveal the socio-economic status of the people two years after relocation. Savings have reduced as a result of relocation. The most commendable feature is the physical housing conditions which have positively impacted the overall quality of life. There are no drastic differences in terms of accessing common places before and after relocation. The findings also reveal that a significant number of respondents did not possess legal deeds. This paper argues the importance of addressing these gaps in order to ensure more sustainable relocation projects in the future.

Keywords Relocation · Relocation options · Relocation process

1 Introduction

High impact disasters have been occurring frequently since 2011 in Sri Lanka, affecting more than 1 million people annually (Sri Lanka Rapid Post Disaster Needs Assessment Floods and Landslides, 2017). Heavy rains, combined with slope instability due to inappropriate land use, triggered the movement of major masses of soil and rocks over houses, public infrastructure and economic activities in several parts of Sri Lanka in 2016 (IOM, 2016). According to the statistics of the Disaster Management Centre, 36,121 people belonging to 9983 families were affected in the Kegalle District. 52 deaths were reported, and 99 people were missing. In addition, 168 houses were irreparably damaged and 1631 were partially damaged.

In the aftermath of this event, the National Building Research Organization (NBRO)—a leading Research and Development institution, a reputed technical service provider and the national focal point for landslide risk management in Sri Lanka—devised a resettlement implementation framework which was approved by the parliament and cabinet of ministers, to relocate families that resided in high risk areas and those who were directly affected by the landslides. The resettlement implementation framework was to be used as a guideline for the Kegalle Resettlement Programme: a planned relocation program aimed at uprooting families residing in areas prone to landslides and resettling them in relatively safer areas. The framework was submitted for the perusal of district secretaries and other relevant officers who were involved in the resettlement process to ensure its successful implementation. Accordingly, the Kegalle District Secretariat undertook the responsibility of resettling families that resided in high risk zones and those whose houses were damaged by the landslide event. This was part of a disaster risk reduction strategy with the technical assistance of the National Building Research Organization (NBRO).

This paper attempts to examine the long term outcomes of planned relocation with specific reference to the Kegalle Resettlement Program. This study has evaluated the status of the relocated community two years after relocation under the Kegalle Resettlement Program, based on five vital indicators: savings, physical housing condition and satisfaction, social capital, access to common places and possession of documents to prove land ownership. Financial savings is an indicator of financial stability and is particularly important to cope with unexpected stresses while the physical housing conditions of a relocated population can either improve or completely restore the lives of people. Social capital is the fabric that sustains a population. Moreover, many scholars have highlighted the need of relocating displaced communities within close proximity to basic services. Finally, deeds that prove land and house ownership play a major role as a collateral in many formal matters in Sri Lanka. All these factors will be assessed in this study.

2 Literature Review

2.1 Conceptualizing Relocation

The terms: 'relocation', 'displacement' and 'resettlement' have been interchangeably used in disaster management scholarship. Nevertheless, it is important to demarcate among these terms before inferences pertaining to theory and/or real world cases of relocation can be made.

Various external shocks—including natural and man-made disasters, situations of conflict, violence and or/revolutionary change and development projects that are geared towards the 'greater good'—often result in the displacement of communities (Cernea, 2002; Scudder, 2005; McDowell, 1996). In the IOM Glossary on Migration, displacement has been defined as "the movement of persons who have been forced or obliged to flee or to leave their homes or places of habitual residence, in particular as a result of or in order to avoid the effects of armed conflict, situations of generalized violence, violations of human rights or natural or human-made disasters" (International Organization for Migration, 2019, p. 55). While the provided definition encompasses both internal [i.e. within national boundaries] and cross-border movement of persons, Principle 6 of the UN Guiding Principles on Internal Displacement interprets displacement as the forced or obligatory movement of persons owing to reasons identified above, exclusively within national boundaries (UNHCR, 2004). While the difference between these two definitions spring from an attempt to demarcate the scope of 'displacement', it is not the purpose of this study to review existing definitions to formulate a furbished definition of 'displacement'. However, the present study is concerned with the compelled movement of persons within the national boundaries of Sri Lanka, following a catastrophic landslide event. Hence, the idea of internal displacement, as opposed to cross border displacement, stands more viable in comprehending victimization of the study's target population.

As discussed, displacement can be caused by a number of reasons based on which three types of displacement can be identified: (1) Development Induced Displacement and Resettlement [DIDR]; (2) Natural Disaster Induced Displacement and Resettlement [NIDR] and (3) Conflict Induced Displacement and Resettlement [CIDR] (CEPA, 2002). Given that displacement victimizes persons, it has been recognized as an issue that demands long term solutions. Illustrating this, Principle 28 of the UN Guiding Principles on Internal Displacement recognizes that it's the primary duty and responsibility of competent authorities is to "establish conditions, as well as provide the means, which allow internally displaced persons to return voluntarily, in safety and with dignity, to their homes or places of habitual residence, or to resettle voluntarily in another part of the country" (UNHCR, 2004, p. 14). Accordingly, the ISAC Framework on Durable Solutions for Internally Displaced Persons identifies relocation as one of the three 'durable solutions' for displacement, the other two solutions being sustainable integration at the place of origin [termed as 'return'] and sustainable local integration in areas where internally displaced persons take refuge [termed as 'local integration] (The Brookings Institution—University of Bern Project on Internal Displacement, 2020; IOM, 2019).

2.2 Planned Relocation: An Outcome of Integrating DRR and CCA into Sustainable Development

External shocks to which communities are exposed are diverse in nature. These shocks often result in the displacement of communities, in extreme cases causing mass displacement (Cernea, 2002; Scudder, 2005; McDowell, 1996). During the last decade, significant attention has been paid to climate induced disasters and their potency of taking human lives and/or dismantling livelihoods and systems of support. This stems from the fact that global platforms like the Intergovernmental Panel on Climate Change's Special Report on Extreme Events [SREX] anticipate a rise in the intensity and the frequency of extreme weather events (IPCC, 2012). Steps have been taken against this background to integrate Disaster Risk Reduction [DRR] and Climate Change Adaptation [CCA] into sustainable development. For instance, the 2030 Agenda for Sustainable Development outlines 17 Sustainable Development Goals [SDG], some of which [Eg: Goal 11 focuse on building safe, resilient and sustainable cities and communities; Goal 13 which calls for measures to strengthen both the global response to and the countries' capacities of dealing with climate change impacts; Goal 15 which entails protecting terrestrial eco-systems from the adverse impacts of climate change] are conducive to DRR and CCA (UNISDR, 2015). Apart from this, the Sendai Framework for DRR 2015–2030 highlights four priorities of action [i.e. (1) understanding disaster risk, (2) strengthening disaster risk governance to manage disaster risk, (3) investing in DRR for resilience and (4) Enhancing disaster preparedness for effective response and to "Build Back Better" in recovery, rehabilitation and reconstruction] that are geared towards protecting the development gains of UN member states from the risk of disasters (UNDRR, 2015).

Emanating from the global recognition of the importance of DRR and CCA for achieving sustainable development, 'planned relocation' of communities has come to be utilized by a number of governing bodies across the globe as both a DRR and a CCA strategy (Piggot-McKellar et al., 2020; UNHCR, 2014). Situating relocation in the context of natural disasters and climate change, the term 'Planned relocation' has been defined as a process where displaced persons move or are assisted to move away from their original habitats or temporary shelters and are settled in a new location while simultaneously being provided with the conditions necessary to rebuild their lives (International Organization for Migration, 2019). This form of relocation can be implemented proactively to minimize the exposure of communities to potential disasters or reactively following a community's exposure to a disaster (UNHCR, 2014). Illustrating the instances where planned relocation is applicable, Warner et al. (2013) identify four categories of people who may be subject to such relocation: (1) people residing in areas which are prone to sudden onset natural disaster (Eg: floods and landslides); (2) people whose livelihoods are threatened from slow onset impacts of climate change (Eg: droughts); (3) people who inhabit lands that are required for mitigation and adaptation projects and (4) people residing in countries or parts of a country which may become uninhabitable due to adverse consequences of climate change (Eg: small island states are challenged by rising sea levels].

UNHCR (2014) makes a distinction between planned relocation and evacuation, stating that planned relocation is a planned and solutions oriented measure, which is usually executed with the intervention of the State, while evacuation is an emergency procedure which involves the rapid physical movement of persons away from an immediate threat to a place of safety. However, in certain instances where the original settlement of the community is uninhabitable and prolonged stay at the place of evacuation is infeasible, planned relocation may follow evacuation. Nevertheless, in light of this, it is possible to fathom that planned relocation is a systematic and a long-term oriented process that does not constitute an emergency response mechanism (The Brookings Institution, 2020; Georgetown University, UNHCR, and IOM, 2015).

The Kegalle Resettlement Program has been implemented by the Government of Sri Lanka as a DRR strategy to uproot people residing in landslide prone areas in Kegalle and to settle them in safer areas. This therefore resembles a case of planned relocation. In this paper, the case has therefore been examined by taking into account the recorded impacts and best practices of planned relocation.

2.3 Recorded Impacts of Planned Relocation

As evident in the discussion above, planned relocation is aimed at reducing the vulnerability of people by reducing their exposure to climatic hazards and thereby improving their resilience (Georgetown University, UNHCR, and IOM, 2015; Usama & Haynes, 2012 cited in Nalau & Handmer, 2018). Planned relocation has therefore been intended to be leveraged as an "adaptive and a transformative development strategy" (Usama & Haynes, 2012 cited in Nalau & Handmer, 2018, p. 1). Conforming to its aims, most cases of planned relocation have been successful in reducing communities' exposure to climatic hazards thus, reducing their fear of an impending disaster and the possible enormity of damage caused by such a disaster. For example, a study conducted on two communities relocated from the Denimanu village in the Yadua island and the Vunidogoloa village in Vanua Levu island in Fiji reveals that both communities felt safer from climate change hazards post-relocation(Piggot Mc-Kellar et al., 2019).

However, ironically, planned relocation programs have often given rise to other forms of vulnerabilities. Elaborating on this is a study conducted on informal households that have been relocated into safer and improved houses under an urban development and disaster mitigation induced resettlement program in Kigali, Rwanda. In this case, many resettlers reported an improvement in their housing conditions post-relocation. However, complaints regarding contextual and cultural sensitivity of houses were common. Resettlers claimed that there was lack of privacy as they were able to see what was happening in their neighbours' homes. Further, the space available for dumping waste inadequate and respondents complained of poor sanitation (Nikuze et al., 2019). Similarly, Wijegunarathna et al. (2018) have explored the long-term satisfaction of relocated communities in relation to physical performance of housing reconstruction projects (flood and Tsunami induced). The authors state that respondents were mildly satisfied about the physical performance of relocation. The study stresses that special attention should be paid to factors such as provisions for alteration and expansion, orientation and layout of the house, number of rooms, lighting and ventilation (Wijegunarathna et al., 2018). Further, a qualitative study carried out on Tsunami victims resettled from Eastern and Southern provinces in Sri Lanka reveals that under most relocation programs, contractors have used poor quality material for housing construction resulting in long term deleterious structural problems like leaking roofs, flooding and seepage from toilets (Hettige & Haigh, 2016).

Planned relocation has also posed unfavourable impacts on people's financial stability. For instance, in the same study by Nikuze et al. (2019) many respondents lost access to wage employment mainly since the new settlements were located far from places providing jobs. Apart from that, renting small housing units and small homes based shops were major sources of income among the resettlers prior to relocation. But, consequent to relocation most respondents had to discontinue these activities owing to lack of space in houses in their new settlements (Nikuze et al., 2019). The resettlers also reported a loss of savings subsequent to displacement and relocation (Nikuze et al., 2019). Further, based on a review of 203 cases of resettlement [both development induced and planned relocation], Piggott-McKellar et al. (2020) note that relocation has often resulted in an increase in financial expenditure of households, partly owing to an improvement in access to facilities like electricity and partly as a result of being compelled to adopt an urbanized lifestyle. For instance, in many cases of relocation, resettlers have been compelled to bear the expenditure of buying food and using public transport to reach schools and markets where prior to relocation these needs were fulfilled free of charge. A rise in expenditure posed a negative effect on household savings, thereby causing a significant decline in resettlers' financial stability (Piggott-McKellar et al., 2020).

Furthermore, evidence shows that cases of planned relocation have dismantled the social fabric of relocated communities. Illustrating this, in the same review Piggott-McKellar et al. (2020) claim that dismantling of social networks, ethnic tensions and conflicts over land and other resources are common outcomes of relocation, specifically in instances where relocated communities have been compelled to integrate with a host community in the new settlement. Nevertheless, drawing on cases of planned relocation in the Carteret Islands, Papua New Guinea, Edwards (2013) presents evidence of certain measures that have been taken to reduce potential disputes between resettlers and host communities. For instance, an exchange program between members of the host community and resettlers was executed to provide both population groups with an opportunity to understand and develop sensitivity to the circumstances of the other. Further, the host communities were financially compensated for having to accommodate the resettlers (Edwards, 2013). Apart from this, certain studies show that adverse impacts of planned relocation on the social networks and systems of support of a relocated community can be mitigated by relocating an entire community as one unit (Piggott-McKellar et al., 2019; Fernando et al., 2017).

Another major concern that has emerged in studies citing real-world cases of planned relocation is the constriction of access to basic services like education, transport and health facilities following relocation (Piggott-McKellar et al., 2019, 2020). In cases where these services have been available in proximity to the relocated site, access has been deprived owing to the increased costs of using the services. For example, with reference to a case of planned relocation in inner Mogolia, Dickinson and Webber (2007) show that although public transport facilities were available to resettlers in their new settlement, the facilities were too expensive to be utilized.

In addition to this, many cases of planned relocation have resulted in a loss of land either because the resettlers have not been compensated with land or because they have not been provided with legal titles to land (Piggott-McKellar et al., 2020; Arnall et al., 2013). In cases where legal titles to land have not been given, the relocatees have suffered from insecurity concerning land tenure (Piggott-McKellar et al., 2020).

2.4 Planned Relocation: Best Practices

Recognizing the tendency of planned relocation programs to compromise development and contradict its intended standing as a development measure, scholars and policy makers have proposed recommendations for best practices to minimize the bleak effects of such relocation. One of the recommendations presented has been to compensate relocated communities with adequate land by taking aspects such as land size and productivity into considerations. This also calls for the issue of land rights to individuals to minimize insecurity concerning land tenure/ensure long term land security (UNHCR, 2014; Piggott-McKellar et al., 2020). Further, it has been noted that the effective execution of planned relocation calls for an acknowledgement of the multi-dimensional nature of vulnerability which extends beyond the physical dimension of vulnerability to include economic, social and perhaps, institutional dimensions of vulnerability (Birkmann, 2011; Connell, 2012; McAdam, 2012). Therefore, planned relocation has to lean towards the sustainable integration of a relocated community into their new setting. It should be accompanied by the provision of financial, humanitarian and development assistance [Eg: by securing undisrupted access to livelihoods and basic services like health and education] to the relocated community until they become fully integrated into their new locations (The Brookings Institution – University of Bern Project on Internal Displa cement, 2010; UNHCR, 2014).

Additionally, improved community participation in the planned relocation process [Eg: in land selection and construction of houses] has been identified as one of the best practices to be followed to ensure success in relocation (Warner et al., 2013; Piggot- McKellar et al., 2019; Fernando et al., 2017). Based on the extent of community participation in housing construction, two broad approaches to housing construction can be delineated: (1) donor driven approach and (2) owner driven approach (Karunasena & Rameezdeen, 2010). A donor driven approach to post-disaster housing reconstruction is where the housing reconstruction process, from the inception to the handing over of housing units to the beneficiaries, is downright handled by the donor agency. The donor driven approach is the traditional approach to post-disaster housing reconstruction (Karunasena & Rameezdeen, 2010). On the other hand, the owner driven approach is a relatively recent approach to post-disaster housing reconstruction. Contrary to the donor driven approach, the owner driven approach involves the provision of financial and technical support for beneficiaries to construct their houses. In the owner driven approach, the beneficiaries have complete control over the housing construction process and therefore enjoy a greater degree of independence in decision making throughout this process (Karunasena & Rameezdeen, 2010). Thus, evidently, an owner driven approach allows for a higher degree of community involvement than a donor driven housing approach (Karunasena & Rameezdeen, 2010; Vithanagama et al., 2015). Planned relocation programs that have utilized a donor driven approach have resulted in more negative relocation outcomes than those that have emulated an owner driven approach (Vithanagama et al., 2015).

Apart from this, scholars have pointed out the importance of taking into account the intra-community vulnerabilities and addressing these vulnerabilities in designing and implementing planned relocation programs (Piggott-McKellar et al., 2020; Warner et al., 2013). That is, certain population groups are subject to a greater degree of vulnerability than others in the context of relocation. For instance, in most relocation projects, a high rate of unemployment following relocation has been recorded among the elderly, in turn leaving them more vulnerable than other population groups (Piggott-McKellar et al., 2020; Warner et al., 2013).

In light of the literature presented above, this study uses financial savings, physical housing conditions, access to social capital, access to basic services, and possession of documents to prove land ownership after relocation, as major indicators to evaluate the long-term outcomes of the Kegalle Resettlement Program.

2.5 Conceptual Framework

This study has used Cernea's (2002) Impoverishment Risks and Reconstruction Model for Resettling Displaced Populations (IRR model) as its conceptual framework. The IRR model elucidates risks of economic, socio-cultural and social welfare related impoverishment associated with the relocation of communities (Cernea, 2002). The model has been built on cases of Development Induced Displacement and Relocation [DIDR]. However, the applicability of the model to planned relocation contexts has been justified in scholarship. For instance, Arnall (2018) draws lessons from cases of DIDR in Asia and Africa to inform future design and implementation of planned relocation projects. Apart from this, Wilmsen and Webber (2015) assert that DIDR and planned relocation are similar in the following respects: (1) both are caused by human actions; (2) both can be planned way in advance of implementation; (3) both pose impacts on people's livelihoods; (4) targeted groups are most often those social groups with less power and (5) there is lack of international protection. Further, the UNHCR (2014) in its report 'Planned Relocation, Disasters and Climate Change: Consolidating Good Practices and Preparing for the Future', notes that certain elements that determine the success or failure of DIDR, and international and national policies and laws that guide DIDR, prove relevant to the context of planned relocation.

Backed by the justified applicability of Cernea's (2002) IRR model to contexts of planned relocation, this study evaluates the long terms impacts of the Kegalle Resettlement Program with specific reference to the impoverishment risks outlined in the model namely:

(1) Landlessness; entails the loss of land pertaining to the original habitat of the relocated community.
(2) Joblessness; refers to the loss of wage employment resulting from relocation lending to unemployment and underemployment among the relocated community.
(3) Homelessness; calls for the loss of housing and shelter.
(4) Marginalization; refers to a situation where individuals are demoted from comparatively higher socioeconomic status to a lower socio economic status as a result of loss of economic power consequent to relocation. Marginalization is often followed by a decline in an individual's social status, thereby leading to social and psychological marginalization.
(5) Increased morbidity and mortality; entails the decline in health conditions of the relocated community through greater exposure to both vector-born diseases and psychological trauma consequent to being relocated to the new environment.
(6) Food insecurity; calls for the possibility of intake of calorie-proteins at a level below the minimum necessary for normal growth and work. Such a possibility is projected based on the tendency for the relocated community's economic power to decline and dismantle the local arrangements of food supply in the original habitat.

(7) Loss of access to common property and services; refers to the relocated community's tendency to lose access to assets that belong to the community like forests, pump water wells and playgrounds and other services like health, education and transport.

(8) Social disarticulation; entails the disintegration of community structures, social networks and ties and the separation from the local organizations of a particular community as a result of relocating households away from the community thereby leading to a dilapidation of social capital.

In line with some of the best practices of planned relocation outlined above, Cernea (2002) proposes the following risk reversals: (1) from landlessness to land-based resettlement; (2) from joblessness to reemployment; (3) from homelessness to house reconstruction; (4) from marginalization to social inclusion; (5) from increased morbidity to improved health care; (6) from food insecurity to adequate nutrition; (7) from loss of access to restoration of community assets and services; and (8) from social disarticulation to networks and community rebuilding, towards reducing impoverishment caused by relocation of communities.

3 Research Methodology

Adhering to the resettlement implementation framework, the government of Sri Lanka constructed houses for families affected by the landslide and for families located in high risk zones. Accordingly, 1729 houses (211 Donor Built, 949 Government resettlement (GRS) and 569 Individual resettlement sites (IRS)) were constructed in 11 DS Divisions in the Kegalle district. 435 households were selected for the study by utilizing a stratified random sampling design. This included respondents from 129 Donor Built, 190 GRS and 116 IRS households. A structured interview schedule was utilized to collect data from household heads. Data collection spanned over a period of 4 months.

This study has also drawn on primary data collected from key informant interviews conducted with NBRO officials. The interviews took the form of unstructured, in-depth interviews and the questions revolved around the relocation process of the Kegalle Resettlement Program.

The Statistical Package for the Social Sciences (SPSS) was used for data entry and analysis. The objective of the study was to explore the status of the community which was resettled under the Kegalle resettlement strategy, two years after relocation by using five indicators which were identified based on secondary literature.

3.1 The Kegalle Resettlement Program

This section discusses the resettlement process of the Kegalle Resettlement Program, which was implemented in Kegalle, Sri Lanka following the 2016 landslides. Information presented in this section has been sourced from key informant interviews conducted with NBRO officials.

The total number of families that were to be resettled in the Kegalle District following the landslides in 2016 was 1631. Beneficiaries were selected based on two conditions; families that were directly and indirectly (those in high risk zones) affected by the landslides. The resettlement implementation framework consisted of the following objectives:

1. To provide guidance and financial assistance to complete a "core-house" for the beneficiaries.
2. To complete the "core-house" using the concept of "build[ing] back better".
3. To ensure that a disaster resilient house is constructed.

The core house consisted of the following features: A minimum floor area of 650 sq. ft, a resilient foundation and a superstructure (as directed by the NBRO), two bedrooms, a kitchen, a permanent roof, a water sealed toilet and a septic tank.

3.1.1 Land Selection

It is vital to select safe land which is not exposed to natural hazards when relocating people. Accordingly, the land selection process under this resettlement program was undertaken by the Divisional Secretariat and approved by the NBRO. Land suitability was evaluated using a set of criteria, such as being free from natural hazards, ease of access to infrastructure (physical and social) and access to livelihoods. With the completion of land selection, the Department of Survey engaged in designing blocking out plans and the minimum block size was stipulated as 10 perches. NBRO then evaluated the block-out plans in terms of land subdivision regulations, storm water management and guidelines on subdivisions in hilly areas. Land preparation (clearing of land, laying of roads and the drainage network, etc.) was undertaken with NBRO recommendations.

3.1.2 House Plans

Planning and designing of plans were undertaken by the NBRO using the "Disaster Resilient Housing Construction" concept which ensures that resilient features are incorporated into every structural and architectural component of the house to resist and protect the house from unforeseen natural disasters. Specific attention is given to structural continuity of the design, the minimum diameter of reinforcement bars, and complying with the standard requirement of construction materials. Housing plans were designed to meet national and international standards, such as being culturally and climatically appropriate, durable and easy to maintain, and allowing for future adaptation. These plans were approved by the cabinet of ministers (Key informant interviews, 2019).

In the meantime, beneficiaries and donors were allowed to submit their own house plans for approval from the NBRO. In the event of house plans not meeting the 'resilient housing construction' requirement, beneficiaries and donors were guided to incorporate resilient features and were requested to modify the plans accordingly.

3.1.3 Housing Types

1. Donor Built Houses
   Under the donor driven approach, houses were constructed by donors with material and labour supply under this approach.
2. Owner Driven
   The Kegalle resettlement program offered the following options to its beneficiaries under the owner driven approach to housing construction:
   Option 01: The government allocated a plot of a minimum 10 perches of land for house construction. Beneficiaries were granted LKR. 1.2 million for house construction in four (04) installments based on the stage of completion (GRS).
   Option 02: Beneficiaries who obtained the approval for Individual Resettlement Sites (IRS) were granted a lump sum of LKR. 0.4 million to purchase land for house construction in addition to LKR. 1.2 million (IRS).
   Option 03: LKR. 1.6 m was provided to purchase the land with a pre-existing house (IRH).

4 Results

4.1 Indicator 1: Financial Savings Before and After Relocation

In general, financial savings is the proportion that is set aside from a person's income for future use. These savings are particularly important to face unforeseen events. As informed by the literature discussed above, savings capacity is a useful indicator that can be used when assessing the financial stability of a community, particularly of displaced and relocated groups that are more vulnerable to poverty.

When examining the patterns of saving before and after relocation, the data reveals that savings have declined after relocation, irrespective of housing type and households employ both formal and informal methods of savings (Fig. 1).

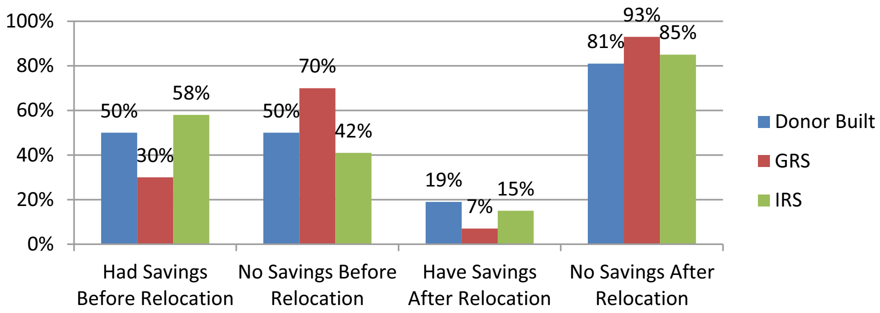

Fig. 1 Savings before and after relocation. *Source* Field Survey (2019)

For an example, in donor built households, savings have reduced to almost less than half compared to savings before relocation (50% (65) before and 19% (25) after). This is mainly due to the increase in household expenses including expenses related to water, gas, electricity and transportation. In relation to the primary data collected from the sample respondents, the average amount of savings both before and after relocation ranged from LKR 1000–5000. A drastic reduction in savings was reported from GRS and IRS housing types. For instance, in GRS households, nearly 30% (55) saved prior to relocation and this had reduced to 7% (18) after relocation, recording a 23% decline in savings. With regard to IRS housing, 58% (68) saved before and only 15% (18) saved after relocation, indicating a 43% reduction in savings. The reasons for these decreasing trends are a change in the location and livelihood activities (loss of jobs, change of employment, lower income coupled with additional expenses), challenges related to adaptation to the new setting, such as time and effort, utilization of existing savings to make alterations in the current house, insufficient funding for house construction, and use of existing savings to cover the increased cost of living.

4.2 *Indicator 2: Physical Housing Conditions*

The state of physical housing conditions consequent to relocation has been assessed by paying attention to indicators like the number of rooms, durability of material used for house construction, access to basic services, land plot size, floor area and space. Findings show that certain housing conditions of the relocated community have improved after relocation irrespective of relocation type. This was evident as the number of rooms, utilization of durable material for house construction and access to electricity and water were favorable compared to the situation before relocation.

Elaborating on this, 12% (14) of those who live in donor built houses had only one bedroom in their previous house. However, as a result of relocation they lived in a house with more than 2 bedrooms in compliance with the 'core house' concept specified in the relocation plan. When discussing the materials used to construct the wall and floor, 13% (15) had responded that their houses in the original setting were made out of mud and 16% (20) stated that the floor in their previous house was also made with mud. Nevertheless, the walls and floor in the new setting were constructed with cement or bricks respectively, which ensures safer homes. In relation to water and electricity, 45% (56) had obtained water from a spring prior to relocation but an individual connection of pipe borne water is available for individual housing units after relocation. Even though 6% (8) did not have electricity before relocation, all housing units have either two-phase or three-phase electricity connections after relocation.

With specific reference to GRS households, 61% (114) lived in a house with one or two bedrooms before relocation. However, all interviewed housing units live in a house with two or more bedrooms after relocation. The roofing of most houses is done with either asbestos or tiles, and cement blocks have been used for walls. 58% (111) obtained water from a spring before relocation and multiple sources (pipe borne water and private wells) are used to obtain water at present.

In terms of IRS households, 39% (42) have lived in a house with 3 rooms prior to relocation. This condition has been upgraded to a certain extent. 16% (19) stated that they currently live in a house with 4 rooms. In addition, 46% (53) had used a spring to obtain water while all respondents used multiple sources to obtain water (pipelines and private wells) after relocation.

The availability of more bedrooms offers privacy and better living conditions, while easy and safe access to water and electricity are factors which contribute to a more favorable living environment. Therefore, the status of the resettled community in terms of the physical condition of housing has been enhanced due to the relocation strategy, which is also commendable as relocation has not only offered a home free from the risk of landslides and other hazards, but has also improved the living conditions of the community.

However, relocation has posed an unfavourable impact on certain other aspects of housing, particularly the land plot size, floor area and space in some housing types. For instance, more than two thirds of respondents from donor built houses are dissatisfied with the land size, the floor area and the availability of space. Space is an important factor, especially if there are children in the family or if members of the household use home gardens for economic means. As opposed to living in a pre-designed, uniform house, people who opted for the IRS housing type had the freedom to use funds to build a house according to their own house plan in a land of their choice. The benefits of providing this freedom of choice are reflected by the high level of satisfaction indicated by those residing in IRS households (See Fig. 2). In other words, those living in Donor Built houses were dissatisfied with the plot size, availability of space and floor area compared to those living in IRS housing.

4.3 Indicator 3: Social Capital

As shown in Fig. 3 the majority of Donor Built and GRS households claimed that their relationships with the community post-relocation were somewhat positive. Further,

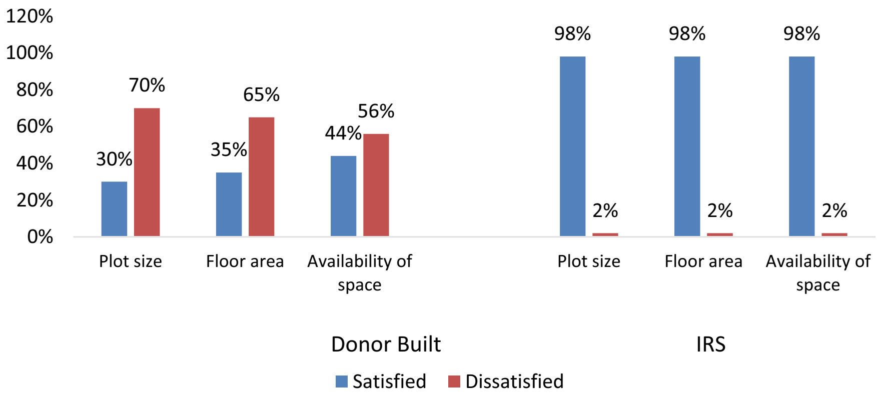

Fig. 2 Comparison of Donor built and IRS households. *Source* Field Data (2019)

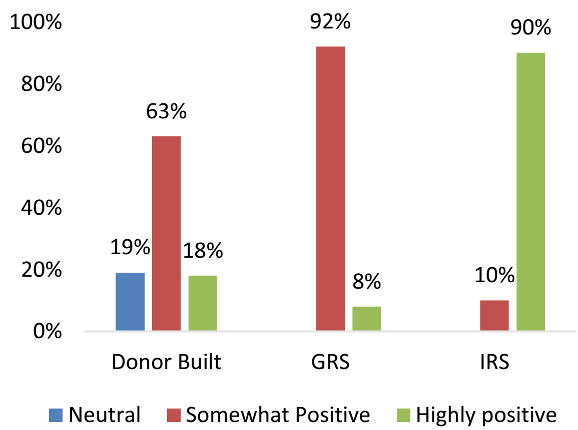

Fig. 3 Satisfaction of community relationships after relocation. *Source* Field Data (2019)

the majority of IRS households reported highly positive community relationships in their post-relocation settings. Thus, data from the present study reveals that relocation has not negatively affected community relationships, but more time may be needed to further strengthen these relationships and enhance social cohesion. However, it is important to note that satisfaction with community relationships is highly positive in IRS settlements compared to GRS and Donor Built households. This is mainly because IRS settlers had the option of considering the neighborhood during the selection process, in addition to many other factors. In this context, one can conclude that the status of this relocated community is favorable in terms of its social capital.

4.4 Indicator 4: Access to Common Services

There are no major changes in the access to schools, hospitals or towns as a result of relocation. Land selection therefore, is successful to a certain extent since it has not worsened the situation of the community, even though more convenience would have been preferred in particular instances. Thus, resettlement in these terms has neither significantly improved nor worsened the situation of the community.

Figure 4 reveals that those in donor built houses have fewer hardships when seeking medical assistance consequent to relocation. Elaborating on this, the proportion of Donor Built households residing within a distance of more than 5 km has decreased post-relocation by 21%. Simultaneously, the percentage of Donor Built households residing within a distance of 2.5 km or less has increased considerably. However, a significant difference in Donor Built households' access to schools before and after relocation cannot be traced. That is, while half of the Donor Built households resided within a distance of 2.5 km or less from a school before relocation, this has not changed subsequent to relocation. In terms of the mode of transportation, a majority travelled by foot to school before and after relocation, and others used buses to travel to the medical center both before and after relocation. Similarly, Donor Built households' access to the nearest town has considerably improved consequent to relocation. This is because the majority of Donor Built households resided within a distance of more than 5 km from the nearest town before relocation, but the majority of these respondents reside within a distance of 1–2.5 km from the nearest town after relocation.

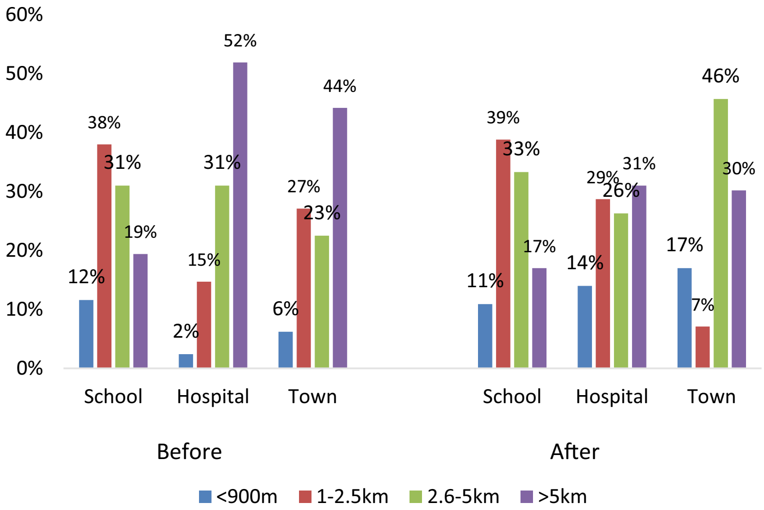

Fig. 4 Access to common services before and after relocation—Donor Built households. *Source* Field Data (2019)

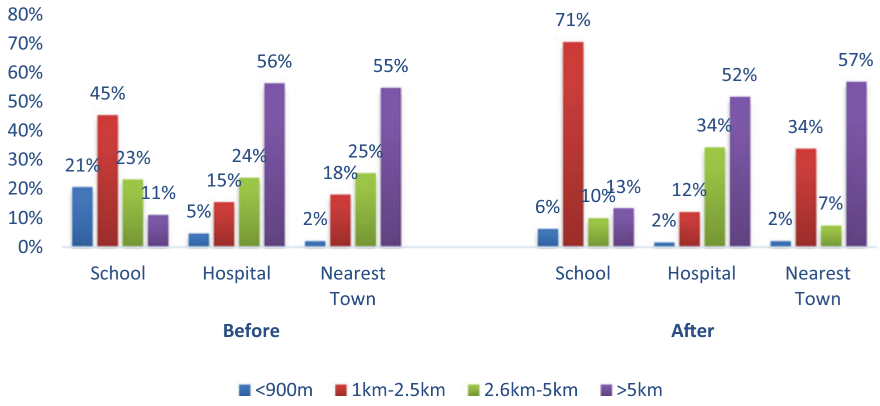

Fig. 5 Access to common services before and after relocation—GRS households. *Source* Field Data (2019)

In the case of GRS households, access to schools has considerably improved following relocation. Elucidating this, data presented in Fig. 5 shows that the percentage of GRS households residing within a distance of 2.5 km or less has increased from 66% before relocation to 77% after relocation. Most respondents travelled to school by foot, both before and after relocation. However, there is no significant improvement or deterioration of GRS households' access to medical facilities and to the nearest town consequent to relocation. This is illustrated by the fact that the majority of GRS households resided within a distance of more than 5 km from a hospital or the nearest town before relocation. This situation has remained the same following relocation.

Figure 6 shows that IRS respondents' access to a school, hospital and the nearest town has not significantly changed following relocation. Elucidating this, while the majority of IRS households resided within a distance of 2.5 km or less from a school before relocation, the situation has remained unchanged to a large extent consequent to relocation. Furthermore, most IRS households resided within a distance of 5 km or more to a hospital and to the nearest town before relocation. This has not been significantly altered following relocation.

4.5 *Indicator 5: Possession of Documents to Prove Land Ownership After Relocation*

In addition to been an asset in itself, possession of a house can serve many purposes. Legal house and land deeds are important documents that are used for certification and legal purposes in Sri Lanka. E.g. for school admissions, gaining water and electricity connections and when applying for financial loans. The findings of the study reveal

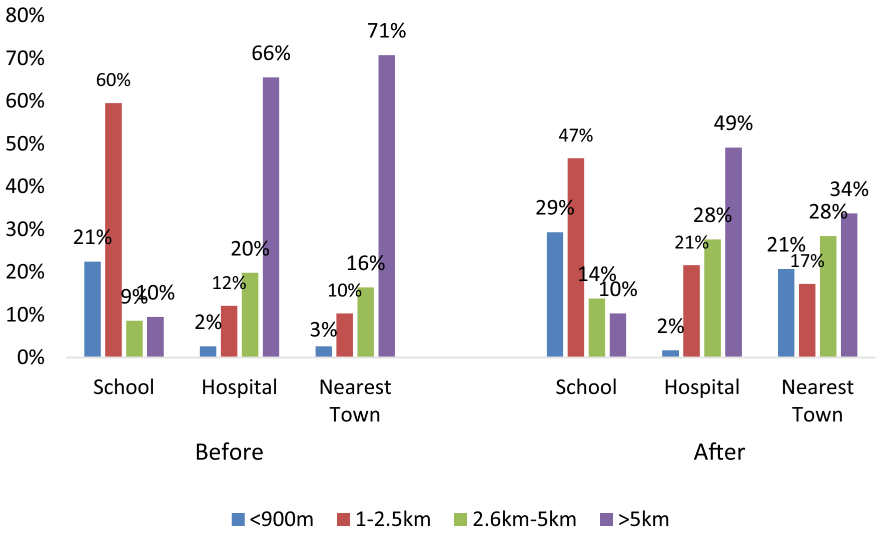

Fig. 6 Access to common services before and after relocation—IRS households. *Source* Field Data (2019)

that there is an urgent need of issuing documents to prove ownership and this process needs to be expedited (Fig. 7).

The findings reveal that Donor Built and GRS households require documents to prove landownership although a small proportion of donor built (28%) and GRS

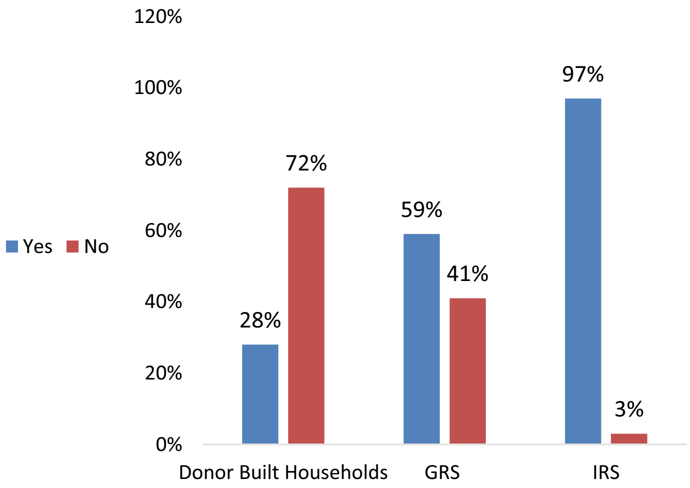

Fig. 7 Possession of legal documents to prove land ownership. *Source* Field Data (2019)

(59%) households have a permit. In total contrast, 97% (112) of IRS households have a legal deed to prove ownership. Therefore, the findings stress the need of expediting the process of issuing legal documents to donor built and GRS settlers.

5 Discussion

This study has evaluated the long term outcomes of the Kegalle Resettlement Program in relation to five indicators, namely, financial savings, physical housing conditions, access to social capital, access to basic services and possession of documents to prove land ownership after relocation.

The findings of this study reveal that the level of household savings have drastically declined after relocation irrespective of the housing type of the respondents. A high level of households has been regarded as indicative of a high level of financial stability (Nikuze et al., 2019; Pig Piggott-McKellar et al., 2020). It is thus, plausible to deduce that relocation has posed a detrimental effect on the financial stability of the respondents and lowered their socio-economic status. In light of Cernea's (2002) IRR model, we contend that the relocatees have been subject to the risk of marginalization following relocation. The reasons cited for a decrease in the level of household savings, such as loss of employment and an increase in expenses on water, gas and electricity, are similar to those highlighted in the studies of Nikuze et al. (2019) and Piggott-McKellar et al. (2020). However, this study also reveals that GRS and IRS households have used their previous savings to make alterations in their house and to compensate for the insufficient funding received for housing construction. GRS and IRS households have made alterations to the current house to cater to their unique family needs. For instance, although the objective of the Kegalle Resettlement Program was to construct a 'core house' of two bedrooms, and the funding for housing construction was provided under all housing options to achieve this, a larger family with many members required a house with a larger number of rooms. Scholars like Piggott-McKellar et al. (2020) and Warner et al. (2013) stress the importance of taking intra-community vulnerabilities when planning and designing relocation programs into consideration. We propose that attention be paid not only to intra-community vulnerabilities but also to the heterogeneities (Eg: in family size and number of depends in a family] within a community in planning and executing planned relocation programs. Planned relocation initiatives that fail to address these heterogeneities evidently result in the marginalization of certain population groups [Eg: those with large families or more dependents in a family].

Further, homelessness stands as a main risk associated with displacement and relocation (Cernea, 2002). People who are victimized by disasters are often deprived of shelter which constitutes a basic human need. Cernea (2002) proposes that this risk be reversed by providing better shelter conditions to the displaced population. Cernea (2002) further asserts that house reconstruction should be aimed at improving the housing conditions of the displaced population rather than restoring their previous housing conditions. The results of this study show that while certain aspects of housing—the number of rooms, utilization of durable material for house construction, and access to electricity and water—have improved among households across all housing types, certain other aspects—the land plot size, floor area and availability of space—have worsened, especially among Donor Built households. This shows that the outcomes of the Kegalle Resettlement Program have not fully aligned with Cernea's (2002) recommendations to improve rather than restore the previous housing conditions of relocatees. It is also important to note that as IRS housing households enjoyed more autonomy in choosing the land and constructing the house, these respondents demonstrated greater satisfaction with the plot size, availability of space and floor area of the house than Donor Built households. Therefore, conforming to the best practices of planned relocation highlighted by scholars like (Warner et al., 2013; Piggot-McKellar et al., 2019; Fernando et al., 2017), the findings of this study depict that greater involvement of relocatees in decision making improves relocatees' satisfaction with relocation outcomes.

Apart from this, results show that relocation has not posed a substantially negative impact on the community relationships of the respondents. With reference to Cernea's (2002) IRR framework, it can be inferred that planned relocation under the Kegalle Resettlement Program has not resulted in social disarticulation. The findings of this study therefore stand in contrast to Piggott-McKellar et al. (2020) who have drawn on cases where planned relocation has resulted in dismantling of relocatees' social networks. The findings of the present study also reveal that IRS households showed a higher level of satisfaction with their current community relationships than Donor Built and GRS respondents. Thus, in addition to the measures of overcoming the risk of social disarticulation outlined by Edwards (2013), Piggott-McKellar et al. (2019), Fernando et al. (2017), we propose improved autonomy and participation of relocatees in decision making as another measure that can be used to mitigate the risk of social disarticulation following relocation. This is because such an approach vests relocatees with greater freedom to opt for a preferred neighbourhood.

Further, the findings of this study reveal that there has not been a significant difference in respondents' access to common services like education, health and markets before and after relocation. The findings of this study thereby contradict the observations of Piggott-McKellar et al. (2019, 2020), Dickinson and Webber (2007). In relation to Cernea's (2002) IRR framework it can be observed that the Kegalle Relocation Program has not resulted in impoverishment caused by loss of access to common property and services. However, it is pivotal to note that a large majority of GRS households did not have convenient access to a hospital or to the nearest town prior to relocation. These limitations have continued to the post-relocation stage. On the other hand, IRS households have given priority to the ease of access to schools when selecting a land for housing construction. The importance given to children's education in Sri Lanka can be related to this trend. These findings are therefore reflective of existing gaps [GRS] and the priorities of the community [IRS] which can be used as crucial indicators by stakeholders.

In addition, results show that significant proportions of Donor Built and GRS households did not have documents to prove landownership. An absence of legal titles to land has in many studies (Eg: Piggott-McKellar et al., 2020; Arnall et al., 2003] been interpreted as a loss of land following planned relocation. Further, ownership rights are seen as a positive attribute of relocation since a legal document is mandatory when applying for financial loans, enrolling children to schools etc. In this sense, the possession of legal house and land deeds is pivotal for realizing various dimensions of wellbeing. For instance, possession of said documents enhances economic wellbeing by enabling access to forms of financial capital like bank loans. Similarly, possession of said documents improves competence and self-worth of relocatees by enabling access to schools. Thus, in light of Cernea's (2002) IRR model, it can be concluded that the Kegalle Resettlement Program has posed a risk of landlessness, particularly on Donor Built and GRS Households. As discussed, this risk can pose a negative effect on the overall wellbeing of Donor Built and GRS households.

6 Conclusion

In line with the global orientation to reduce disaster risk, house recovery and construction in the Kegalle relocation project has been geared towards the construction of hazard resilient houses. However, in an attempt to reduce vulnerability caused by exposure to landslides, the Kegalle Relocation Project has overlooked other dimensions of vulnerability like vulnerabilities caused by a loss of employment, loss of access to land and an increase in expenditure. Thus, vulnerability should be considered as a multi-faceted phenomenon in the future design and execution of planned relocation projects. Further, planned relocation programs should not only address the intra-community vulnerabilities, as emphasized in the literature, but also take into account the heterogeneities within a targeted community. This calls for a deviation from the widely used planned relocation approach where the same program allocations are made to all households within the targeted community. An approach to planned relocation that allows for the customization of program allocations, assisted by an initial community assessment to cater to the heterogeneities within the community as far as possible, should be embraced. Additionally, future initiatives of planned relocation should seek to enhance community participation and autonomy in decision making so that relocation outcomes can be vastly improved.

Planned relocation has been justified against a backdrop that advocates the integration of DRR and CCA into sustainable development. Nevertheless, most attempts at planned relocation have not adequately addressed the breath and the overarching nature of 'sustainable development'. For this reason, many scholars and policy makers have questioned the validity and efficacy of planned relocation as a development measure. This study therefore sheds light onto some steps that can be taken to strengthen the validity of planned relocation as a transformative and an adaptive sustainable development measure.

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Development of a Legume Based Disaster Resilient Emergency Food Product

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Abstract Development of rapid cooking, cost-effective and consumer-friendly food products with a handsome shelf life is a timely requirement with a view to soothe the grievance of disaster-vulnerable community while preventing the outbreak of food-borne and food governed illnesses and provisioning of food and nutritional security. Under this circumstance, a legume-based emergency food product was developed using green gram which can be stored, handled, and consumed conveniently as a disaster response diet for the affected community.

Keywords Disaster response diet · Emergency food · Food security · Green gram · Rapid-cooking

1 Introduction

According to WHO/EHA (2002, p. 3) disaster is "an occurrence of disrupting the normal conditions of existence and causing a level of suffering that exceeds the capacity of adjustment of the affected community". Disasters can be induced either naturally or due to human activities. Flood, landslides, droughts, wildfire, tsunami, earthquakes, and cyclones are some popular examples for natural disasters whereas, industrial accidents, terrorism, biological weapons, and cyber-attacks can be identified as the most common man-made and technological disasters.

There is a higher possibility of food safety chaos following disastrous situations including the outbreak of communicable diseases and nutritional deficiencies. Crowding, inadequate provide of unpolluted water, poor sanitary practices, and unhygienic conditions during food processing, storage, distribution, and consumption can lead to certain food safety issues such as diarrhea, cholera, typhoid fever and hepatitis

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A (World Health Organization, 2006). Hence, the provision of nutritious, safe, and secure food for fulfilling the dietary requirements of the affected communities is an important aspect of disaster resilience (Cooper, 2018). Under this circumstance, the development of food systems for providing safe and secure, nutritious, and accessible food even in harsh situations has gained an enormous interest throughout the world. This development is called "resilient food systems" (Biehl et al., 2018). As stated in ReliefWeb (2015), the development of a resilient food system is mainly focused on building a resilient food production system, resilient food supply system, and socio-economic resilient.

With the occurrence of a sudden disastrous situation, certain groups of affected communities get isolated either in their own houses or in disaster relief centers with limited food availability. Hence, maintaining adequate storage of emergency food is an important part of disaster response preparedness. Generally, it is recommended to have a tolerable level of emergency food storage for several days at the household level. Simply, food items that are high in nutritional and calorie value, that do not require refrigeration, water or special preparation techniques are identified as emergency foods (Texas A&M AgriLife Extension, 2004; The Federal Emergency Management Agency, 2004). Further, these products should not be salty (because that can increase the thirst) and should be properly packed in affordable sizes (University of California, 2009; Texas A&M AgriLife Extension, 2004).

Wien and Sabaté (2015), have proposed a "three-phase multidimensional approach" ((phase 1) Nutrient density, (phase 2) Scoring system, (phase 3) Disaster response diet) for planning disaster response diets. Therein, they have scored 11 nutrient-dense food groups considering four major food selection criteria namely, (1) nutrient density, (2) storage and handling properties, (3) ease of preparation, and (4) cultural acceptance/individual tolerance. According to their study, plant-based food groups including dry cereals, nuts, dried fruits, grains, and legumes impart favorable qualities with respect to the four distinct disaster response diets planning criteria for the purpose of planning a disaster response diet.

Legumes are widely grown throughout the world and can be identified as rich sources of calories, proteins, dietary fiber, resistant starch, vitamins, minerals as well as phytochemicals (including antioxidants, phytosterols, and bioactive carbohydrates) (Pasha et al., 2011; Rajiv et al., 2012). Singh et al. (2004, p. 977) have described legumes as "the edible fruits or seeds of pod-bearing plants belonging to the order Leguminosae". Green gram (Mung bean), Chickpea, Red gram, Black gram, Kidney bean, Cowpea, Soya, and Lentil are some important grain legumes consumed by millions of people in semi-arid and tropical regions in many Asian and African countries.

Green gram (*Vigna radiate* L.) beans are considered as one of the cheapest and richest sources for plant protein (Pasha et al., 2011) including albumin and globulin as the main storage proteins along with certain essential amino acids such as leucine, valine, isoleucine, but lack in sulfur-containing amino acids (methionine and cysteine) (Mubarak, 2005; Zhu et al., 2018). The nutritional composition of green gram includes 51% of carbohydrate, 24–26% of protein, 4% of mineral, and 3% of vitamins (Mondal et al., 2012). Moreover, carbohydrates in green gram are easily digestible and hence, show a comparatively lower possibility of flatulence compared to the other legumes (Ganesan & Xu, 2018). Further, Green gram beans and sprouts are rich in essential fatty acids (Pasha et al., 2011). Green gram beans and green gram sprouts can also be considered as a group of functional food due to the availability of bioactive phytochemicals with a high potential of antioxidant properties (Ganesan & Xu, 2018; Hou et al., 2019; Pasha et al., 2011) as well as anti-bacterial, anti-fungal, anti-viral, anti-inflammatory cardioprotective, hepatoprotective, anti-diabetic, anti-cancer, anti-obesity, potent chemopreventive and hypolipidemic properties (Ganesan & Xu, 2018; Hou et al., 2019).

Generally, the application of different processing methods such as germination, dehulling, fermentation, and cooking can contribute to reduce or eliminate anti-nutritional factors available in green gram beans. As an example, Wang et al. (2015) have observed that the germination process can reduce the phytic acid content of green gram by 76.0% and increase the bioavailability of certain minerals like Zn and Fe. Due to the higher protein content and hypoallergenic properties of green gram, it is recommended as a supplement for preparing weaning food for infants (Hou et al., 2019). Further, Ganesan and Xu (2018) have stated that due to the palatability and nutritional quality of green gram, it can be recommended as an Iron-rich dilatory source for infants and children. Since, green gram is a widely cultivated legume mostly in Asian countries as well as in certain dry regions of southern Europe and warmer parts of United States and Canada (Hou et al., 2019; Zhu et al., 2018), it is easily accessible for all personals in social cross profile.

Early preparedness and continuous supply of emergent, nutritious, healthy food products that are convenient to be handled and consumed is an important disaster-resilient step to cope up with the major and short dietary requirements during natural calamities. As a highly nutritious and functional food, green gram can be supplied as a major breakfast meal for fulfilling the dietary requirements of the affected community. Generally, boiling is the most popular way of consuming green gram. However, it is a time-consuming process where, the raw seeds are subjected to soaking in cold water for approximately 6–8 h and boiled until the seeds become soft (for about 30–35 min) (Navaratne, 2015). Hence, the preparation of such food items can be problematic under calamitous conditions. Thus, the purpose of the current study was to develop sensorially acceptable rapid cooking green gram as an emergency disaster response diet for fulfilling the dietary requirements of the affected community.

2 Materials and Methods

2.1 Sample Preparation

Green grams were purchased from locally registered supermarket chains in Colombo, Sri Lanka. The purchased stuff were cleaned to remove stones, damaged beans (insect, mold & mechanical), immature beans, and other foreign materials. The

Table 1 Green gram samples prepared from each treatment combination with the control

Sample number	Treatment	Sample number	Treatment
Control	–	7	CS; D
1	HT; CS; D	8	CS; DF; D
2	HT; CS; DF; D	9	NHS; D
3	HT; NHS; D	10	NHS; DF; D
4	HT; NHS; DF; D	11	HS; D
5	HT; HS; D	12	HS; DF; D
6	HT; HS; DF; D		

Heat treatment (HT): Green gram were heated in a hot air oven (Universal oven; UN30) at 80 ± 2 °C for three hours
Cold soaking (CS); Green gram were soaked in excess amount of water (25 ± 2 °C) overnight
Hot soaking with $NaHCO_3$ (NHS); Green gram were soaked in excess amount of water (70 ± 2 °C) with 1% $NaHCO_3$ for three hours
Hot soaking without $NaHCO_3$ (HS); Green gram were soaked in excess amount of water (70 ± 2 °C) for three hours
Deep freezing (DF); Green gram were deep freeze for eight hours
Dehydrating (D); Green gram were dehydrated in a hot air oven (Universal oven; UN30) at 70 ± 2 °C for six hours

cleaned green gram was subjected to user/ producer friendly and cost-effective treatment combinations with a view to produce rapid cooking green gram as given in Table 1.

2.2 Cooking Time

The cooking time was determined with reference to the method described by Singh et al. (2004) with slight modifications. Therein, approximately 50 g of green gram from each treatment combination and the control were added into boiling water (800 ml) in stainless steel cooking pans. Thereafter, the pans were partially closed from the lids and let the samples to be boiled under the medium flame of the gas burner. After 10 min of boiling, one bean was withdrawn from the bulk without interrupting the boiling and the bean was pressed between the thumb and the forefinger to determine the degree of cooking. Likewise, the degree of cooking of the beans was tested for every 1–2 min interval to obtain the cooking time. The cooking time was considered as the time required for cooking approximately 90% of the beans completely.

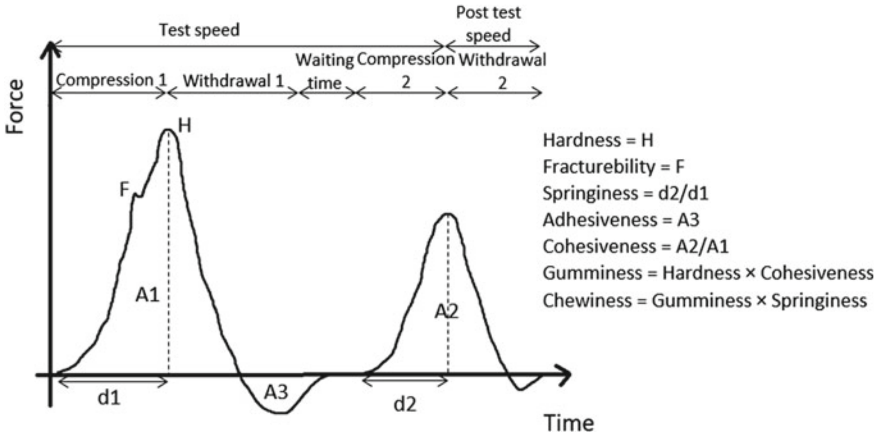

Fig. 1 Typical compression curve of instrumental texture profile analysis

2.3 Texture Profile Analysis

Texture profile analysis of the 12 cooked green gram samples in each treatment combination was determined with reference to the method described by Nisha et al. (2006) using CT3 texture profile analyzer with slight modifications. Therein, TA10 probe; 2 test cycles; 2 mm/s test speed; 2 mm distance; 5 kg cell load were considered. All the readings were averaged of 10 individual measurements. Hardness (g), Adhesiveness, Springiness (mm), Cohesiveness, Gumminess (g), Chewiness (mJ) were obtained with respect to the compression curve (Fig. 1) of force (g) vs time (s) using Brookfield TextureProCT Software TA-CT-PAD-AY.

2.4 Evaluation of Moisture Content

The moisture content of well-dried green gram sample with acceptable cooking qualities was evaluated according to the oven drying method (AOAC standard method).

2.5 Statistical Analysis

All the parametric data were statistically analyzed using Minitab 17 Statistical software following one way ANOVA test by considering 95% as the confidence interval.

3 Results and Discussion

Cooking quality is considered as a function of cooking time and it is an important quality parameter of the palatability, texture, and digestibility of legumes (Sasikala et al., 2011). According to Table 2, all treated green gram samples used for the current study were boiled within 23 min without undergoing a pre-soaking in cold water. Of these samples, sample number 8 (CS; DF; D) has the lowest cooking time of 11.75 ± 1.26 min ($P \leq 0.05$). The control sample (raw green gram boiled without pre-soaking in cold water) has taken the highest cooking time (33 ± 0.82 min) and it is significantly different ($P \leq 0.05$) to the all other twelve treatment combinations. Nevertheless, the control sample had an uneven cooking quality characteristic because it contained a considerable amount of orally hard beans.

In preparing the sample number 8, green gram was subjected to overnight cold soaking to allow the beans to absorb water molecules into the beans. Thus, the well-soaked beans become fully hydrated with water and tend to increase the volume. Thereafter, beans were undergone deep freezing for 8 h to form ice crystals in the cotyledons of the beans. Those ice crystals are caused to form hairy scale cracks in the cotyledons itself. During the drying step, these cracks are further expanded and formed a well porous bean structure. When these beans are subjected to re-cooking, the formed cracks facilitate to absorb hot boiling water into the beans rapidly and cook the beans within a short period.

Texture profile analysis is an imitative test resembling the textural sensation within the human mouth to evaluate the human perception with respect to the textural attributes (mechanical, geometrical, and surface) of the food (Rosenthal, 1999).

Table 2 Cooking time of the each green gram sample

Sample number	Cooking time (min)
Control	$33.25^{a} \pm 0.96$
1	$20.00^{cde} \pm 0.82$
2	$19.25^{de} \pm 0.96$
3	$19.00^{de} \pm 0.82$
4	$20.00^{cde} \pm 0.82$
5	$21.50^{bcd} \pm 1.29$
6	$21.25^{bcd} \pm 0.96$
7	$17.50^{e} \pm 1.29$
8	$11.75^{f} \pm 1.26$
9	$19.50^{cde} \pm 1.29$
10	$22.00^{bc} \pm 0.82$
11	$23.00^{b} \pm 0.82$
12	$21.25^{bcd} \pm 1.26$

Values with different superscripts are significantly different at 0.05 significant level

Texture profile analysis is an important parameter for evaluating the cooking quality of a legume sample as well (Sasikala et al., 2011). When evaluating the texture profile of cooked legumes and grains, the textural characteristics can highly depend on the microstructure of the beans as well as on physical and chemical changes occurring during the cooking process (Singh et al., 2004). According to the texture profile analysis results given in Table 3, Green gram sample number 1 (HT; CS; D) has the lowest hardness among the 12 green gram samples. However, the value does not show a significant difference ($P \geq 0.05$) to the hardness of the green gram sample number 8 (CS; DF; D). Green gram sample number 9 (NHS; D) has the highest hardness among the 12 samples. Generally, the application of $NaHCO_3$ into soaking water can soften the beans and quicken the cooking process. However, the current study shows somewhat different results showing a higher cooking time and higher hardness for green gram samples treated with $NaHCO_3$ (sample number 3 (HT; NHS; D), number 4 (HT; NHS; DF; D), number 9 (NHS; D) and number 10 (NHS; DF; D)).

The adhesiveness of all the samples does not show a significant difference ($P \geq 0.05$) to each other. Springiness is also an important texture property that represent the cooking quality of a grain sample, which is the degree to which a cooked grain return to its original position after removing the partial compression whereas, cohesiveness is a parameter that represents the ability of the cooked grain to withstand the second deformation (Yu et al., 2017). Green gram sample number 7 (CS; D) has the highest springiness value and the green gram sample number 12 (HS; DF; D) has the lowest springiness value. While Green gram sample number 7 (CS; D) shows the highest cohesiveness value, the lowest was given by green gram sample number 11 (HS; D). Concerning the sensorial perception, gumminess is the energy required to disintegrate a food for swallowing and chewiness is the energy required for chewing food until it becomes suitable for swallowing (Kasapis & Bannikova, 2017; Lyon et al., 2000). According to the results given in Table 3, green gram sample number 3 (HT; NHS; D) and number 11 (HS; D) has the lowest gumminess (g) and green gram sample number 12 (HS; DF; D) has the lowest chewiness (mJ). However, gumminess and chewiness of green gram sample number 8 (CS; DF; D) does not show significant difference ($P \geq 0.05$) to these samples that showed the lowest gumminess and chewiness values.

Reykdal (2018) has stated that the grains with moisture content less than 13% cease the growth of most mites and molds, and the grains with less than 10% moisture content has a very low susceptibility for the development of most of the insects and pests. Hence, low moisture content and proper storage conditions (storage temperature, relative humidity, and good hygienic practices) lead to higher storage stability of the grains (Likhayo et al., 2018; Mohapatra et al., 2015). Since the moisture content of rapid cooking green gram is around 8.06 ± 0.41%, it has higher shelf stability if it is packed in proper packaging material with higher barrier properties, and stored under proper storage conditions. For instance, Kumari (2017) has observed that hermetic bags can be used for the safe storage of green gram for about 33 weeks with minimum quality defects. Further, according to Sharon et al. (2015) black gram samples (moisture content 9%) stored at 20 °C showed storage stability of 42 weeks with appreciable viability and microbial stability.

Table 3 Texture profile analysis of twelve treated green gram samples

Sample number	Hardness (g)	Adhesiveness	Springiness (mm)	Cohesiveness	Gumminess (g)	Chewiness (mJ)
1	$235.0^{e} \pm 32.2$	$0.01^{a} \pm 0.09$	$1.14^{ab} \pm 0.12$	$0.250^{ab} \pm 0.10$	$58.3^{ab} \pm 15.40$	$0.633^{bc} \pm 0.21$
2	$405.0^{a} \pm 17.9$	$0.17^{a} \pm 0.21$	$1.01^{bcd} \pm 0.20$	$0.133^{cd} \pm 0.05$	$53.00^{ab} \pm 15.82$	$0.533^{bcd} \pm 0.19$
3	$258.3^{de} \pm 51.4$	$0.13^{a} \pm 0.14$	$0.89^{d} \pm 0.09$	$0.137^{cd} \pm 0.05$	$36.0^{b} \pm 10.73$	$0.300^{cd} \pm 0.09$
4	$358.3^{abc} \pm 67.3$	$0.13^{a} \pm 0.21$	$0.89^{d} \pm 0.10$	$0.117^{cd} \pm 0.05$	$38.00^{b} \pm 14.94$	$0.333^{bcd} \pm 0.14$
5	$308.3^{bcde} \pm 80.7$	$0.03^{a} \pm 0.05$	$0.91^{d} \pm 0.03$	$0.145^{cd} \pm 0.01$	$52.67^{ab} \pm 10.21$	$0.433^{bcd} \pm 0.23$
6	$246.7^{de} \pm 30.4$	$0.07^{a} \pm 0.05$	$0.96^{cd} \pm 0.06$	$0.173^{bc} \pm 0.04$	$44.0^{b} \pm 13.36$	$0.433^{bcd} \pm 0.19$
7	$357.3^{abc} \pm 38.0$	$0.17^{a} \pm 0.15$	$1.19^{a} \pm 0.05$	$0.270^{a} \pm 0.04$	$89.67^{a} \pm 13.87$	$1.000^{a} \pm 0.09$
8	$295.0^{bcde} \pm 25.4$	$0.15^{a} \pm 0.14$	$1.15^{ab} \pm 0.12$	$0.143^{cd} \pm 0.06$	$68.0^{ab} \pm 29.8$	$0.400^{bcd} \pm 0.09$
9	$410.0^{a} \pm 4.47$	$0.15^{a} \pm 0.13$	$0.86^{d} \pm 0.01$	$0.105^{cd} \pm 0.06$	$43.5^{ab} \pm 15.5$	$0.350^{bcd} \pm 0.23$
10	$335.0^{abcd} \pm 79.1$	$0.23^{a} \pm 0.05$	$1.12^{abc} \pm 0.01$	$0.140^{cd} \pm 0.01$	$62.67^{ab} \pm 9.27$	$0.667^{ab} \pm 0.19$
11	$382.33^{ab} \pm 20.13$	$0.07^{a} \pm 0.05$	$0.87^{d} \pm 0.01$	$0.057^{d} \pm 0.02$	$36.00^{b} \pm 14.39$	$0.433^{bcd} \pm 0.23$
12	$273.3^{cde} \pm 33.9$	$0.16^{a} \pm 0.10$	$0.84^{d} \pm 0.02$	$0.073^{d} \pm 0.01$	$39.00^{b} \pm 7.6$	$0.267^{d} \pm 0.10$

Values in the same column with different superscripts are significantly different at 0.05 significant level

As far as estimation of the selling cost of the rapid cooking green gram is concerned, the average selling cost of 1 kg of raw green gram is 200 LKR (approximately $1 according to the central bank of Sri Lanka, 2020) with effect from 23rd April 2020 (Shazuli, 2020). On the basis of this price tag and considering the cost analysis, the approximate cost of 1 kg of rapid cooking green gram prepared from sample number 8 would be around 285.00 LKR (approximately $1.53). However, due to the lower moisture content, the number of people to be served with 1 kg of rapid cooking green gram is higher than that of raw green gram.

Since rapid cooking green gram does not contain any preservatives and artificial colorings, it is safe and suitable for all the persons in the social cross profile. In the case of disastrous situations, hundreds of people are gathering in disaster relief centers. Therefore, the supply of safe and secure, nutritious major meals with minimum cooking time is a critical requirement. Since the developed green gram can be rapidly cooked and can be consumed even with scraped coconut and/or chili paste with or without adding salt, it is an ideal food for consuming as a major meal in disastrous situations. Nevertheless, green gram can be soaked and deep freeze according to treatment 8, and dried at a higher temperature (80–90 °C). Then the product can be easily ground to get a powdered form of a product with somewhat coarser particles and packed in a proper packaging material, particularly in moisture barrier. This ground product itself can be directly consumed as an emergency food product even in a calamitous situation without any pre-processing or cooking along with either liquid milk or sugar or scrapped coconut.

4 Conclusion

Green gram is to be subjected for cold soaking by immersing them overnight in cold water (25 ± 2 °C), and thereafter these beans are to be undergone deep freezing (8 h) and dehydration at 70 °C for 6 h to convert them into rapid cooking form. The developed rapid cooking green gram has higher storage stability along with acceptable cooking qualities, which is a critical requirement during natural disasters, particularly in flood situations. On the other hand, since green gram is a nutritious food, it is an ideal food for calamitous situations, especially for third world developing countries, where protein sources are meager under severe drought condition.

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Applicability of Drywall Technology in Disaster Relocation Projects: Time-Based Performance Analysis

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Abstract The use of traditional wet wall construction in disaster relocation projects occupies a substantial share of the total project duration. Although many drywall options show positive signs in terms of time performance, its application is quite rare. This research, therefore, investigated the time-based performance of different drywall technologies in the context of disaster relocation projects. Following a comprehensive literature review, a round of preliminary expert interviews was conducted to narrow down the drywall technology options considering the applicability to developing context. The types were evaluated based on on-site and off-site construction efficiency. Next, a questionnaire survey was conducted with a sample of 48 experts to evaluate the time performance of selected drywall technologies against the on-site and off-site construction efficiency. The data were analysed for the Mean Weighted Rates yielding a ranked list of ten drywall technologies. Gypsum board and Calcium Silicate panels scored as the top two technologies. The research, therefore, provides a sound basis to select drywall options for disaster-resilient house designs, rehabilitation guideline preparation, community awareness process, and performing research and development in the field of disaster relocation.

1 Introduction

Naturally triggered catastrophes are becoming a frequent phenomenon striking heavily on communities. The Christchurch earthquake in New Zealand in 2011, as well as the 2004 Indian Ocean earthquake and Tsunami, were some eye-openers in this regard that left thousands of people homeless (Gjerde & Sylva, 2017). In such a scenario, 'time' becomes a critical parameter in satisfying the shelter demand of those

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displaced people. Besides Statistical data of the National Building Research Organisation (NBRO) in Sri Lanka reveals that the people, who live in high hazardous zones of landslides should be rehabilitated instantaneously to avoid causalities (National Building Research Organisation, 2018). Evacuating the people from regions that are highly exposed to natural disasters creates further time pressures on resettlements.

Time management in disaster relocation projects is challenging and the majority of such bottlenecks are related to construction technologies i.e. supply chain disruptions, poor construction skills, resource shortages (Chang et al., 2010). Among all building technologies, wall construction technology has a major impact on the overall efficiency, in managing the construction of multiple shelters such as in post-disaster resettlement projects (Chang et al., 2010) since the wall construction takes about 44% of the total project duration (Jayawardene & Panditha, 2003).

Although developed countries use different drywall technologies for residential construction, developing countries such as Sri Lanka are still into conventional wet wall construction technologies (Sabau et al., 2018). Inevitably, it would be essential to re-think the efficiency of the technology behind wall construction; likely drywall technology due to its on-site installation advantages over the time requirement (Danane & Wagh, 2018). Thus, the supremacy of drywall technologies against the wet wall construction was established theoretically and time performances of different drywall technologies were assessed against disaster relocation projects' requirements driven by the existing gap in the application of suitable drywall technologies in the context of developing countries.

2 Research Methodology

Research methodology paves the way to create knowledge comprehended with data collection techniques and analysis tools. Pragmatically, a mixed approach was followed in this research avoiding the drawbacks of quantitative and qualitative approaches taken alone whilst offering the individual strengths of both. As a developing country exposing to frequent natural disasters which also facilitates convenient data collection options, Sri Lanka was chosen for empirical data collection.

Accordingly, a round of preliminary interviews comprising three interviews with professional experts in the field of wall construction was conducted initially, with two purposes i.e. (i) Narrow down the available drywall technology options considering the applicability to the developing context, and (ii) Explore the branches of time efficiency requirements of disaster relocation projects.

Next, a questionnaire survey was conducted using a sample of 48 professionals and the sample was stratified into four groups considering the expert background of respondents as represented in Table 1.

From Table 1, it was perceptible that more than 50% of the sample is at least experts in either drywall technologies or disaster relocation projects, which indicates a favourable cross-section. Further experts in disaster relocation projects were

Table 1 Experience categorization of respondents

Experience category	Sample size	Percentage (%)
Experts only in disaster relocation projects	12	25.00
Experts only in drywall technologies	10	20.83
Experts in both disaster relocation projects and drywall technologies	4	8.33
Other construction professionals	22	45.83
Total	48	100.00

33.33% of the sample, which signals the cohesiveness of the sample for evaluating the wall construction requirements of disaster relocation projects, whilst drywall experts (29.17%) intended to bring insights on different drywall technologies. Other construction experts were holding considerable knowledge in the construction industry; therefore, they were beneficial in terms of the diversity of the expertise. Thus, for the empirical data collection, sample is gathered from a population considering three main directional areas disaster relocation projects, drywall technologies and other construction professionals whereas all relevant to the given context. Hence the sample is solidly representative.

Qualitative data were subjected to content analysis and the data collected from the questionnaire survey were analysed using statistical tools with the aid of the SPSS 20 software package, as well as the Microsoft Excel software. The main statistical tools used for the study were Mean Weighted Rating (MWR), standard deviation, and skewness. Standard deviation was involved in assessing the reliability of the data set, and skewness represented the normality of data distribution as indicated in Table 2 (Saunders et al., 2009).

MWR was used to score the parameters as indicated in Eq. 1 where the responses were weighted regards to the level of experience of the respondents. The weighting decisions were verified referring to the previous knowledge (Gunasena, 2010).

$$MWR = \frac{\sum_{i=0}^{N}(W_i \times F_i)}{N} \tag{1}$$

Equation 1. Mean Weighted Rating (Saunders et al. 2009).

Where: MWR: Mean Weighted Rating for an attribute, F_i: Frequency of responses, N: Total number in the responses, W: Constant giving to weight each case.

Table 2 Interpretation of skewness values (Saunders et al. 2009)

Skewness value (s)	Interpretation of data distribution
(−0.5) < s < 0.5	Approximately symmetric
(−1) < s < (−0.5) or 0.5 < s < 1	Moderately skewed
s < (−1) or s > 1	Highly skewed

Table 3 Interpretation of MWR values (Gunasena, 2010)

MWR value	Interpretation	Colour code
4-5	Strongly higher feasibility	
3-4	Higher feasibility	
2-3	Average feasibility	
1-2	Lower feasibility	
0-1	Strongly lower feasibility	

Transfigured five levels for interpreting MWR values are shown in Table 3. A colour code was also developed in the aid of data presentation.

The Overall Score of each drywall technology was calculated based on the Eq. 2 to rank the drywall technologies based on their overall time performance (Both R1 and R2) as depicted below.

$$Overall\ Score = \frac{\sum_{i=0}^{N}(MWR_{R1DTi} \times MWR_{R1}) + \sum_{i=0}^{N}(MWR_{R2DTi} \times MWR_{R2})}{MWR_{R1} + MWR_{R2}} \quad (2)$$

Equation2 Overall Score.

Where: MWR_{R1DTi}: Mean Weighted Rating of a certain dry wall technology under R1, MWR_{R2DTi}: Mean Weighted Rating of a certain dry wall technology under R2, MWR_{R1} : Mean Weighted Rating of R1, MWR_{R2} : Mean Weighted Rating of R2.

3 Literature Review

Literature synthesised knowledge on "time as a key concern for wall construction in disaster relocation projects", "the deficiency of current wet wall technologies in terms of time performance" and then on the "time performance of different drywall technologies was reviewed".

3.1 Time as a Key Concern for Wall Construction in Disaster Relocation Projects

The key challenges that direct the emergency shelter requirement of disaster relocation can be identified as;

- Need to establish the normal routine of those homeless immediately (Badri et al., 2006),

- Need to prevent spontaneous irregular resettlements on unsafe lands (Chang et al., 2010),
- Need to prevent or at least minimise the causalities of natural catastrophes by resettling families at risk immediately (Badri et al., 2006).

Therefore, in the disaster relocation scenario, time becomes paramount (Jha & Iyer, 2007) out of the three main constraints for any construction project as identified by the theory of iron-triangle i.e. time, cost, and quality (Hughes & Williams, 1991). Furthermore, the probable causalities due to the risk of natural catastrophes can greatly be prevented or at least minimised by providing immediate housing solutions for families at risk (Vijekumara & Weerasinghe, 2016). Specifically, being a time-sensitive construction element, wall construction makes a substantial impact over the on-time performance of the disaster relocation projects (Chang et al., 2010). Hence, utilising the technological advancements pertaining to the time efficiency requirement, as an innovative construction technology dry wall construction has become prominent over wet wall construction technologies (Danane et al., 2018). Hence the next sub section would compare and contrast the wet-wall technology and drywall technology on their time-based performance.

3.2 Comparison Between Wet-Wall Technology and Drywall Technology on Their Time-Based Performance

Although wet wall construction is widely known to be a conventional technology, it is heavily inherited with real-time drawbacks in the disaster relocation project scenario. The provision for alteration and modification of interior partitions with conventional masonry walls is relatively low due to higher time consumption. Celentano et al. (2018) stated that brick masonry has caused the construction process lengthier, as well as ineffective in the case of the 2004 tsunami in Indonesia as it comparatively consumed a higher time with its highly labour-intensive nature. Further, on-site testing standards are not proactively used for wet wall typologies of disaster relocation projects, resulting in low-grade buildings with construction errors (Condeixa et al., 2015).

Hence, overcoming time-related deficiencies of current wet wall construction technologies scrutinised before, drywall technologies are appraised as a remedial measure within the context of disaster relocation project scenarios. Thus, using precast building systems such as drywall partitioning reduces the number of operations at the site while bringing down the construction time (Jayawardene & Panditha, 2003). Further, utilising the technological advancements of the drywall technology, it is reported to have eight times a faster construction process than conventional (Tamboli et al., 2018). Hence, in terms of the time performance, wet wall construction becomes an obsolete practice in disaster relocation projects (Chang et al., 2010) with drywall technology as an alternative filling the deficiencies of current wet wall construction. A range of drywall technologies are available (Ovca, 2016) and the time-related benefits of those are discussed in the next section.

3.3 Time-Based Performance of Drywall Technology in Disaster Relocation Projects

Amongst various drywall types identified from Table 4, Gypsum boards are claimed as a faster option since they can be installed three to four times faster than conventional masonry walls (Danane and Wagh, 2018; Tamboli et al., 2018). The efficiency of installing the Calcium Silicate wall panel board is 13 times compared to the masonry walls (Si, 2018). To quote an example from the American context, by comparing certain design approaches, Ovca (2016) suggested a passive approach comprising a ZIP panel system and plywood sheathing to reduce the time consumption of disaster rehabilitation projects. In another example, an actual model catering the needs of wind and tsunami hazards, constructed with Expanded Polystyrene Sandwich (EPS) panel at Yatiyanthota, Sri Lanka (Munasinghe, 2018), consumes a noticeably lesser time (one and half days of unskilled labour) to construct 130 square foot (sqft) room. Previous literature sources have further assessed embodied energy, cost, toxicity, local availability, and maintainability of the DURRA board, MDF board, and gypsum board (Athambawa et al., 2014). Fire, wind, and energy performance of Galvanized steel wire mesh polystyrene sandwich panels, ALC panel, and OSB board have also been previously addressed (Gunasena, 2010).

Publications titled on the performance of different drywall technologies are shortlisted in Table 4.

Based on the literature synthesis, it can be argued that choosing proper local drywall materials enhances the construction speed considerably without a significant impact on the expense due to the shorter transportation (Athambawa et al., 2014; Chang et al., 2010). Consequently, establishing the contextual applicability of various drywall partitioning technologies for disaster relocation project scenarios is significant in fulfilling immediate shelter requirements.

4 Findings—Preliminary Interviews

The preliminary interviews were used to consolidate the synthesised literature in developing the data collection tool for the questionnaire survey. Three professionals have assisted; two of them were experts in the field of disaster relocation projects and the other expert was from the field of drywall technologies. The initial round has classified the time efficiency requirement of wall construction into two basic categories as on-site and off-site time consumption efficiency-related aspects considering the

Table 4 Drywall technologies

Drywall type	References	Drywall type	References
Gypsum board partitions	Danane and Wagh (2018)	Galvanized steel wire mesh polystyrene sandwich panels	Chen (2018)
ZIP panel system	Ovca (2016)	Cement bonded particleboard	Danane and Wagh (2018)
Expanded Polystyrene Sandwich (EPS) panels	Munasinghe (2018)	Autoclaved Lightweight Concrete (ALC) board	Chen (2018)
Glass fibre reinforced gypsum panel	Bardhan and Debnath (2018)	Oriented Standard Board (OSB)—Composite material	Chen (2018)
Cellulose fibre cement composite panels	Ardanuy and Claramunt (2015)	Calcium silicate wall panel board	Si (2018)
Medium Density Fibre (MDF) board	Athambawa et al. (2014)	Light-gauge Steel Framed (LSF) walls	Dias et al. (2019)
Paddy straw composite board (DURRA)	Athambawa et al. (2014)	Lightweight Sandwich Membrane partition wall (LSM)	Mateus et al. (2011)

sequence of the wall construction process. Next, the list of drywall technologies identified from the literature review was shortlisted coming into a consensus of all three experts considering the applicability to the studied context. Accordingly, Galvanized steel wire mesh Polystyrene sandwich panels, ZIP panel system, Galvanised steel wire mesh cement Polystyrene sandwich panels, Light-gauge Steel Framed (LSF) walls, and Lightweight Sandwich Membrane partition wall (LSM) were rejected due to insufficient availability to be exhausted for mass residential projects such as post-disaster relocation. Ultimately, a list of ten drywall technologies was finalised for further evaluation (refer Table 6).

5 Findings—The Questionnaire Survey

An expert questionnaire survey where the respondents specialised in a particular subject area are sampled (Kachroo & Kachen, 2018), was used firstly to rate time-based wall construction requirements in disaster relocation project scenarios, and secondly to rate different drywall technologies against those two specific time-based requirements. Consequently, it was intended to develop a scorecard comprising the ten drywall technologies and to rank those reflecting their time performances. The ordinal data were captured via a Likert scale of 1–5.

Table 5 Descriptive statistics of wall construction requirements

The time-related wall construction requirement	MWR	Std. deviation	Skewness statistic	Skewness Std. error
R1. Efficiency of on-site time Consumption	4.59 (MWR_{R1})	0.495	−0.367	0.254
R2. Efficiency of off-site time Consumption	3.88 (MWR_{R2})	0.91	0.247	0.254

5.1 Prioritising Time-Related Wall Construction Requirements in Disaster Relocation Projects Scenarios

Respondents of the survey were initially asked to provide an overall rating on two basic time-related requirements, (i) on-site time consumption efficiency, and (ii) off-site time consumption efficiency using a 1–5 Likert scale to examine the applicability for the context of a developing country. By referring to Table 5, it is observable that MWR of the on-site time consumption efficiency is relatively higher than the off-site time consumption efficiency.

The impact of R1 towards the overall time performance of disaster relocation projects, therefore, falls within the "strongly higher" range while R2 falls within the "higher" range.

The skewness of the data (refer Table 5) indicates that the distribution is approximately symmetric, containing the value in between −0.5 and 0.5. A lower standard deviation imitates the higher reliability of the data set. Hence, the study directs towards the need of prioritising different drywall technologies against time-related wall construction requirements of disaster relocation projects.

5.2 Prioritising Drywall Technologies Against Time-Related Wall Construction Requirements of Disaster Relocation Projects

Questionnaire respondents were further asked to rate the 10 drywall technologies validated through the preliminary interviews, considering their importance against R1 and R2 using the same Likert scale of 1–5. Thus, Table 6 reveals the descriptive statistics of different drywall technologies.

The skewness of the data (refer Table 6) indicates that the distribution is approximately symmetric since the value is in between −0.5 and 0.5. A lower standard deviation imitates the higher reliability of the data set. Accordingly, most of the data in the set are normally distributed and highly reliable. None of the data in the

Table 6 Sample descriptive statistics of drywall technologies against time-related wall construction requirements

Time efficiency requirement	Drywall technologies under each time-based requirement	MWR	Std. deviation	Skewness Statistic	Skewness Std. Error
The efficiency of off-site time consumption	Gypsum board partitions	4.54	0.501	−0.164	0.258
	Calcium silicate wall panel board	4.43	0.91	−0.956	0.258
	Glass fibre reinforced gypsum panel	4.07	0.625	−0.048	0.258
	EPS panels	3.99	0.47	−0.04	0.258
	MDF	3.98	0.821	0.043	0.258
	OSB	3.87	1.065	−0.333	0.258
	Cellulose fiber cement composite panels	3.84	0.913	−0.609	0.258
	DURRA	3.84	0.913	−0.609	0.258
	Cement bonded particle board	3.82	1.006	−0.32	0.258
	ALC board	3.67	1.138	−0.23	0.258
The efficiency of on-site time consumption	Gypsum board partitions	4.45	0.711	−0.905	0.258
	Calcium silicate wall panel board	4.36	0.849	−0.762	0.258
	Cement bonded particle board	4.1	1.046	−0.898	0.258
	EPS panels	3.98	0.482	−0.066	0.258
	MDF	3.89	0.855	0.225	0.258
	DURRA	3.87	0.567	−0.023	0.258
	Glass fibre reinforced gypsum panel	3.86	0.574	−0.003	0.258

(continued)

Table 6 (continued)

Time efficiency requirement	Drywall technologies under each time-based requirement	MWR	Std. deviation	Skewness Statistic	Skewness Std. Error
	OSB	3.82	0.883	−0.769	0.258
	Cellulose Fibre cement composite panels	3.66	0.478	−0.664	0.258
	ALC board	3.25	1.014	0.565	0.258

set is highly skewed. After, a scorecard would be developed on drywall technologies' performances against time-related wall construction requirements of disaster relocation projects under next subsection.

5.3 *Development of the Scorecard: Drywall Technologies' Performances Against Time-Related Wall Construction Requirements of Disaster Relocation Projects*

Drywall technologies were graded in the scorecard against time-based wall construction requirements by assigning MWR as scores (refer Fig. 1). The scorecard facilitates selecting feasible drywall technologies under each of the two wall construction requirements (R1 and R2). The score of each factor in the scorecard demonstrates its relative feasibility, while the colour code enhances the visual clarity of the score.

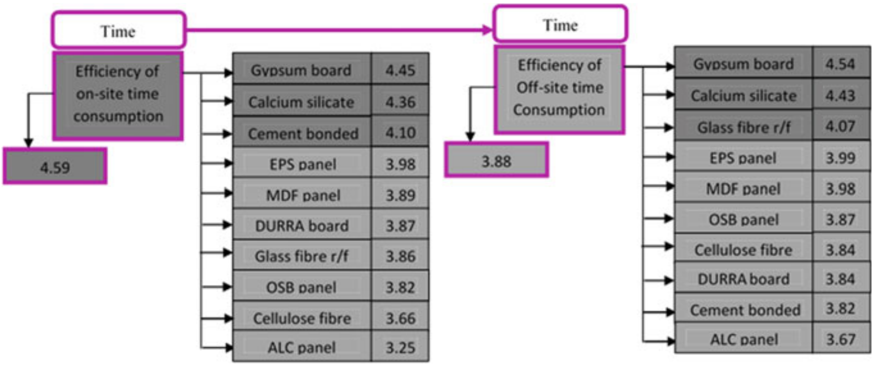

Fig. 1 Scorecard on the time performance of drywall technologies for disaster relocation projects

1. • Gypsum board partitions
2. • Calcium silicate wall panel board
3. • Expanded Polystyrene Sandwich (EPS) panels
4. • Cement bonded particle board
5. • Glass fibre reinforced gypsum panel
6. • Medium Density Fibre (MDF) board
7. • Paddy straw composite board (DURRA)
8. • Oriented Standard Board (OSB)
9. • Cellulose fiber cement composite panels
10. • Autoclaved Lightweight Concrete board (ALC)

Fig. 2 Ranked list of drywall technologies for the time performance of disaster relocation

Accordingly, for Sri Lanka, Gypsum Board, Calcium Silicate Panel, and Cement Bonded Particle Board are pointed out as the most feasible technologies under R1.

All the short-listed drywall technologies are ranked in the scorecard within the strongly higher or higher feasibility range, thus, advantageous towards enhancing project time performance. Although, the first three technologies under each requirement can be recommended for the best performance.

All ten drywall technologies were ranked based on the Overall Score values derived considering the overall time performance of each drywall technology during the disaster relocation projects as shown in Fig. 2.

Rankings demonstrate the relative feasibility of a particular technology's possible contribution to the time performance of disaster relocation projects. Thereby, the Gypsum board can be identified as the best time-based solution for wall construction in disaster relocation projects. Similar results were assured by Tamboli et al. (2018) referring to a different context.

Two experts espoused the developed scorecard and the ranked drywall list for disaster relocation project scenarios to their knowledge and experience on drywall technologies, as well as disaster relocation projects, therefore, the findings were externally validated.

6 Discussion

Drywall technologies offer significant time-related benefits for wall construction in disaster relocation projects compared to wet wall technologies. Accordingly, gypsum board, calcium silicate panel, EPS panels and cement-bonded particle boards are figured out as the most feasible technologies based on their time consumption efficiency. Moreover, the literature sources of Danane and Wagh (2018) and Si (2018) further verified the less time consumption of gypsum boards and calcium silicate panels over the other technologies. Further, cement-based boards such as calcium silicate wall panels, cement-bonded particleboard, and cellulose fiber-cement composite panels are identified as efficient solutions for interior partitioning in flood disaster relocation projects based on existing literature (Garvin et al., 2005). Adding to this, in another example, Munasinghe (2018) stated that in an actual model constructed at Yatiyanthota, Sri Lanka, Expanded Polystyrene Sandwich (EPS) panel partitioning has consumed relatively lesser time which is around one and half days of unskilled labour to construct 130 square foot (sqft) room. Thus, the identified key drywall technologies could be further verified through the existing literature.

7 Conclusion and Recommendations

Time-based performance of projects and subsequent project activities are crucial for mass residential projects, especially in the disaster relocation project scenario, globally. In contributing such expectations, the study assessed how wall construction time passage can be narrowed by using modular construction methods based on a comparison amongst the drywall technology options. Time consumption efficiency of wall construction can be assessed in two ways i.e. (i) on-site, and (ii) off-site time consumption efficiency out of which on-site efficiency becomes a hotspot in disaster relocation. The findings so far would be applicable to the global context as well.

Accordingly, a scorecard was developed based on the empirical data collected from Sri Lanka. The ranked drywall list would facilitate the selection process of an appropriate drywall technology for wall construction of disaster relocation projects in developing countries in particular. The findings are generalizable to the developing countries considering the similar nature in responding to the disaster situations. Considering overall time performances, Gypsum board partitions and Calcium Silicate wall panel boards can be suggested as most suited, leaving Expanded Polystyrene Sandwich (EPS) panels, Cement bonded particle board and Glass fibre reinforced gypsum panels behind respectively in the given context. Thus, recommended drywall technologies could be adapted in disaster-resilient house designs, rehabilitation guideline preparation, community awareness process, and performing research and development in the context of a developing country. However, a content specific ranking could produce considering a particular developed context, with bit of a data collection and feeding into the already established mechanism through the research.

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Research and Innovation in the Context of Disaster Resilience in the Sri Lankan Higher Education Sector

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Abstract The significance of developing robust multi-stakeholder Disaster Resilience (DR) mechanisms has multiplied in the last few decades. Accordingly, countries around the world have taken measures to strengthen the capacity of Higher Education Institutions (HEIs) with regard to DR as they have the potential of generating research-based guidelines and developing interventions. It is in this context that this paper attempts to investigate the status of Research and Innovation (R&I) within HEIs in Sri Lanka. It examines the existing policies, infrastructure and the status of the research staff in relation to R&I. Key informant interviews were conducted with a purposively selected sample of academics from national universities, policy makers, and directors who are actively engaged in DR and Disaster Management (DM). The findings reveal that Sri Lanka lacks a national policy on R&I, which in turn has reduced the support received by researchers from HEIs. Furthermore, lack of systematic training, absence of multi-stakeholder participation and limited permanent research staff were identified as major barriers. In addition, the findings suggest that Sri Lankan HEIs should focus on establishing a national policy to develop R&I, allocate more funds to carryout R&I within HEIs and establish a permanent cadre who is highly qualified in research to further improve R&I capacities. It concludes that the prevailing capacities of Sri Lankan HEIs are inadequate and emphasizes the importance of taking prompt measures to improve R&I capacities in HEIs.

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1 Introduction

Disaster Management (DM) and Disaster Resilience (DR) have been recognized as paramount for protecting the development gains of nations (ESCAP, 2017; UNISDR, 2015). Elaborating on this, eradication of poverty has been identified as a hallmark of development in the post-2015 Sustainable Development agenda and its predecessor: the Millennium Development Goals (MDGs) (United Nations, 2020). Scholars have often illustrated the disproportionate impacts of disasters asserting that poorer communities are more detrimentally affected by disasters (whether natural or manmade) than their relatively well-off counterparts (ESCAP, 2017; Hallegatte et al., 2020). This is because they tend to settle in high risk areas given the cheaper land prices; resulting in greater exposure to disasters on one hand and because they have limited access to assets indicating lower adaptive capacity and thus, a higher degree of vulnerability to disasters on the other (ESCAP, 2017; Hallegatte et al., 2020). Therefore, disasters often result in poor communities been trapped in the cycle of poverty and the continuation of poverty beyond the present generation. Hence, it is vital that DM and DR be mainstreamed into the national development agenda of a country (ESCAP, 2017) for the poor to benefit from development gains of a nation. Having said this, it is important to note that the world has evolved into a knowledge society, also referred to as a knowledge economy where human intellect is regarded as the fundamental resource driving growth and development. Knowledge produced leveraging intellectual abilities now function as the engine of global growth and development replacing former factors of production like physical labour, natural resources and mechanical processes (Bell, 1974; Kearney, 2009; Jacob & Meek, 2013). The emergence of the knowledge society has been viewed as a consequence of the 'Third Industrial Revolution' which marks a period of social transformation steered by technological advancements and the advent of globalization in the 1990s (Kearney, 2009). Hence, the key question we pose is how DM and DR can be strengthened in a global context where cognitive resources engineer development. An attempt to address this question calls for an exploration of the role of Research and Innovation (R&I) as a vehicle of knowledge production.

Owing to the centrality of knowledge production in a global knowledge society, the importance of enhancing the quality and intensity of R&I as a vehicle of knowledge production has come to be widely discussed both in academia and policy platforms. Although producers of knowledge in the global knowledge economy are diverse (Bell, 1967), Higher Education Institutes (HEIs) including universities stand as one of the main producers of knowledge, among others, given their inherent research function and innovation capacities (Jacob & Meek, 2013; Kearney, 2009). Elucidating this, Jacob and Meek (2013, p. 333) claim, "Despite the growing heterogeneity of knowledge producers, the university remains the key resource for scientific human capital accumulation and is the incubator for many initial international research networks, in addition to being a research dynamo in its own right".

A variety of factors that determine the efficacy and strength of R&I as a vehicle of knowledge production have been outlined in the literature. Primarily, the 'stakeholder concept' theorizes that knowledge production [in this case through R&I] should be viewed as a process that requires the participation of multiple stakeholders (Meek & Davies, 2009; Sadana, 2008). While HEIs like public and private universities act as producers of knowledge through direct engagement in R&I, HEIs do not function in a vacuum. Rather, HEIs would ideally interact with national, international and industrial funders to adequately finance R&I activities; evaluators or monitors of research to verify R&I activities and users of research including the government, industries and the general public so that the outputs of R&I permeate and benefit the wider society (Meek & Davies, 2009; Sadana, 2008).

Secondly, Ho (2007) identifies pertinence as one of the three critical success factors for research, the other two being quality[1] and sustainability.[2] Pertinence measures the extent to which research and innovation based on such research "meet a business need, economic development or a societal challenge" (Ho, 2007, p. 3). This indicates the importance of orienting R&I to address real-world developmental needs and issues. Apart from this, the importance of bridging the 'Knowledge Divide' and the resulting 'Research Gap' between 'the core' and 'the periphery' has been emphasized (Kearney, 2009). The 'Knowledge Divide' refers to a discrepancy in living conditions between countries that have better access to cum capacities for processing knowledge and others that do not. Most low and middle-income countries remain weak in terms of their R&I base and knowledge production (El Kaffass, 2007; Ramirez, 2008) mainly owing to a lack of research funds and investment in training research personnel (Kearney, 2009). Nevertheless, improving the R&I capacities of low- and middle-income countries is important to address their local development issues and needs. Delineating this, the UNESCO (2005) highlights that it is important for each nation to develop its individual version of a global knowledge society where knowledge production through R&I facilitates the country's national development agenda. Similarly, Kearney (2009) argues that it is vital for a country to have its own R&I community to allow for local analysis and stimulate national innovation systems. Kearney (2009), thus proposes that a strong national commitment to R&I, a culture of inquiry, advancement in research skills and an improved capacity to use external research and knowledge are needed to increase the efficacy and strength of R&I in low and middle-income countries.

In addition to this, over the past decade, most governments have faced the challenge of striking a balance between widening access to tertiary education and promoting R&I in HEIs (Kearney, 2009). These stems constitute the dual role of HEIs as knowledge providers and knowledge producers. Nevertheless, with the aim

[1] Quality is an attribute that defines the value of research outcomes, measured by "its degree of excellence, superior to existing knowledge or products" (Ho, 2007, p.3).

[2] Sustainability measured by the ability of the research to sustain for an extended period of time and its potential to grow further (Ho, 2007, p.3).

of establishing consensus between these two functions, Trowler and Wareham (2007) outline seven dimensions of a 'Teaching/Research Nexus': (1) Learners do research; (2) Teachers do research; (3) Teachers and learners research together; (4) Research embedded in the curriculum, (5) Research culture influences teaching and learning; (6) The nexus, the university and its environment and (7) Teaching and learning influences research (see Table 1).While each of these dimensions have their own costs and benefits, the framework provides a guideline for a balance between the research and teaching functions of HEIs so that R&I components are not undermined. Similarly, Jacob and Meek (2013) emphasize the significance of researcher mobility and international collaboration in fortifying the outcomes of R&I. Promoting researcher mobility offers a number of benefits especially to low and middle-income countries in the form of technology and knowledge transfers, enhanced research competencies and higher educational aspirations (Gaillard & Gaillard, 1997; Woolley et al. 2008). Further, commenting on ways of strengthening R&I in HEIs, Yutronic (2007) stresses on defining assessment procedures to ensure the recruitment of staff whose research skills and competencies are at an acceptable level.

Taking into consideration both the globally acknowledged significance of DM and DR for development and the mission of knowledge production in a global knowledge society, enhancing the quality and intensity of Research and Innovation (R&I) addressing the subject matter of disaster resilience stands of prime importance. Research and Innovation are important aspects of Disaster Resilience in any country as they contribute to the advancement of multiple dimensions of the country including the generation of new knowledge, expansion of existing bodies of knowledge, economic development and enhancement of technology. Against the backdrop of a global knowledge society, countries encourage and promote R&I activities and enthusiastically keep records on the progress of these two aspects. It is in this context that this paper attempts to generate a holistic and comprehensive picture of the present situation of R&I in relation to one of the key stakeholders of R&I: Higher Education Institutes of Sri Lanka. With the aim of further improving the accuracy and rigor of the paper, specific attention is paid to R&I activities carried out in relation to Disaster Resilience (DR) and Disaster Management (DM), due to the great significance that DR & DM hold at present given the increasing trend of natural disasters in the country. This paper is divided into several sections an introduction, Higher Education Institutes (HEIs) in Sri Lanka, participant categories & profiles, purpose of the interviews, findings, and the overall summary and conclusions. The findings are presented under the themes; importance of R&I, capacity building, policies to promote R&I in HEIs, training and development initiatives for R&I in HEIs, enablers that support R&I in HEIs, barriers that hinder R&I in HEIs and suggestions to improve R&I in HEIs.

Table 1 Dimensions of the teaching/research Nexus

• Meaning of "Nexus"	• Practices	• Suggested benefits	• Possible Dysfunctions
• Learners do research	• Research-based learning approach Research community practices replicated—peer review, publication on web or paper	• Range of skills developed • Range of concepts developed; Epistemological awareness developed	• Learning too slow to cover curriculum • Patchy coverage of curriculum
• Teachers do research	• Teaching cutting edge material Teaching about their research	• Skills developed in research, re-used in teaching • Develops thinking abilities of teachers	• Teachers spend most of their time and energy on research to the exclusion of students • Teaching assistants employed to replace teachers engaged on research resulting in student exposure to lower levels of expertise
• Teachers and learners research together	• Students as research assistants, Co-operative planning and implementation of research projects	• Co-operative relationship between teachers and learners	• Learning too slow to cover curriculum • Patchy coverage of curriculum • Students effectively unpaid research assistants
• Research embedded in the curriculum	• Research-based learning approach used • Cutting edge research and knowledge incorporated in curriculum design	• Action research feeds into quality review and enhancement	• Patchy coverage of curriculum, Transmission of essential knowledge poorly effected
• Research culture influences teaching and learning	• Teachers and students discuss research together • Research culture permeates practices in teaching	• Research culture provides a motivational context for teaching and learning	• Research prioritised over teaching, leaving non-researchers among the staff as well as students feeling abandoned

(continued)

Table 1 (continued)

• Meaning of "Nexus"	• Practices	• Suggested benefits	• Possible Dysfunctions
• The nexus, the university and its environment	• Both teaching and research are linked into the commercial environment and local communities, addressing needs and solving problems Knowledge transfer takes place	• Research-teaching links offer opportunities for knowledge transfer, The nexus can indicate improved institutional structures and strategies • The nexus can indicate improved national policies on enhancing teaching and research	• The needs and priorities of employers and others take precedence in the academy • Pure research and critical approaches to society and become marginalised
• Teaching and learning influences research	• Research projects refined and developed as a result of discussion with students (particularly in areas of preparation for professional practice)	• Mutual benefit to both teaching and research in a feedback loop Skills developed in teaching re-used in research	• Substantive disciplinary research becomes sidelined • Low quality pedagogical research begins to predominate because of lack of training in methods and relevant social scientific disciplines

Source Adopted from Trowler and Wareham (2007)

2 Research and Innovation in the Context of Sri Lankan Universities

The public university system, which is the backbone of Sri Lanka's HE sectors, began with the Ceylon University College, established at the Royal College premises, Colombo in 1921. The Ceylon University College was elevated to a well-developed university in the year 1942. At present, there are 15 universities, 3 campuses and 18 Higher Education institutes under the wing of the University Grants Commission (UGC). The UGC was established as the apex body of the Sri Lankan university system in 1978 under the Universities Act No. 16 of 1978. UGC is responsible for planning and coordination of university education, allocating funds to HEIs, maintaining academic standards, regulation & administration of HEIs and admission of students.

In terms of R&I in Sri Lankan HEIs, multiple reports have identified the significance of promoting R&I to improve the productivity and efficacy of the HE system. A comprehensive report by Sivasegaram and Senaratne (2012) has made important recommendations to the Ministry of Higher Education, the UGC and HEIs. Some of the recommendations were providing funding for research activities, facilitating foreign exposure to academics, promoting entrepreneurial and research ventures, policy formulation, enforcing appropriate financial regulations, performance evaluation with predefined indicators and promoting student centered education. Another report discussing the significance of promoting innovation is compiled by Wijesinghe and Perera (2012) who emphasize the need for an effective combination of technology and innovation to facilitate integration with the global economy and to enhance the country's ability to face international competition.

When examining the Disaster Resilience Research base within HEIs in Sri Lanka, University of Peradeniya was the first state university which took the initiative of teaching courses related to Disaster Management in Sri Lanka. Following the precedence set by University of Peradeniya, a large number of leading HEIs offer Disaster Management focused courses and modules in both undergraduate and postgraduate programmes in the country. Significantly, these are not limited to teaching theories and concepts of DR & DM but also pay special attention to encourage young academics to engage in research activities related to the sector.

University of Moratuwa conducts research activities on social resilience and disaster mitigation. University of Peradeniya is further involved in research projects pertaining to hazard mitigation, resilience, landslides, and mitigation. Both University of Colombo and University of Ruhuna engage in disaster related research in a number of areas including relocation, agriculture, food security and community based early warning systems, natural and social ecosystems, and ecosystem-based adaptation.

3 Methodology

The findings of this study are based on the analysis of thirty-six semi-structured interviews conducted with selected policy makers (at the national level), managers of the UGC and senior researchers. Interview guidelines were developed based on a detailed literature review carried out by the project partners. Secondary sources such as the UGC's website, archival records, secondary data and publications were perused to fill the gaps in data with respect to the current situation pertaining to R&I in the country.

Interview data was further triangulated with a follow-up questionnaire survey that was carried out to identify the current level of capacity in terms of R&I in HEIs related to DR. The survey instrument consisted of a series of close-ended questions on a 5-point Likert scale and a binary scale. The questionnaire also consisted of several open-ended questions to further probe the answers. The collected data was analysed using the Statistical Package for Social Sciences (SPSS).

4 Findings

This section summarizes the views of the respondents on the importance of R&I, current context and gaps related to capacity building, policies that promote R&I, training and development initiatives for R&I and enablers, barriers and suggestions to improve R&I in HEIs.

4.1 Views on R&I Capacity Building in HEIs: Current Context and Gaps

During the semi-structured interviews, all policy makers and managers emphasized the value of R&I in terms of upgrading the standards for universities. It was also mentioned that it is equally important to pay attention to knowledge production and usability of insightful research findings to enhance the research impact. According to this assumption, they further suggested that universities are responsible to play advisory roles by providing research-based guidance to the Disaster Management Center (DMC) to improve their capacity to deal effectively with disasters.

In this context, many respondents suggested that it would be most appropriate for researchers from HEIs to appoint a technical committee to support the DMC.

4.2 Policies Related to Research and Innovation

Policies have a great influence on R&I capacity building of any given country. It is important that a policy has sustainability. All the interviewees held the opinion that Sri Lanka does not have a national policy on R&I carried out by HEI's and even existing policies are often subject to change according to the will of politicians to suffice their narrow and selfish propaganda. As one of the interviewees said, "One of the symptoms in our system is the lack of continuity". Some respondents believed that there are adequate national policies in terms of teaching but that these policies should be improved to accommodate research initiatives.

Apart from that, the University Act does not provide sufficient emphasis on R&I needs; some interviewees mentioned that many academics are not fully aware about their availability even though all policy documents are compiled and available at the universities for reference.

4.3 Views on the Policies to Promote R&I in HEIs—Current Context and Gaps

This section of the paper discusses the attitudes and opinions expressed by respondents on the availability, accessibility, and adequacy of policies to promote R&I in HEIs in Sri Lanka.

According to some of the respondents, the overall policies within the university system to support R&I appear to be adequate. The major policies behind research engagements are linked to the research allowance policy and promotions to senior lecturer and professor grades. According to the promotion criteria, no academic can be promoted to the post of professor unless a given minimum has been obtained for research as per the prevailing UGC circular.

All tenured staff members are entitled to sabbatical leave with passage for both staff member and spouse to be engaged in research, teaching or consultancy in any local or international institution. Publications by academics in international journals with citations are rewarded. University of Ruhuna initiated the Vice Chancellor's Award for best scholars, best innovators, best builders of international relations, best fund raisers and best young scientists etc. in 2001 to promote R&I. Research has been incorporated into the quality assurance program of the university at institutional and program level assessments. It is a university policy that all young staff should participate in programmes conducted by the Staff Development Centre in order to be promoted to senior lecturer grades. The university organizes a symposium that is a general forum for academics to present their programs and research findings every academic year. In addition, almost all the faculties conduct their annual symposiums as international events in most cases to share research findings. There are university grant schemes for best research proposals submitted by academics, travel grant schemes and supporting programmes to publish research papers in international journals.

The respondents further revealed that most information regarding policies can be found on the UGC website and in the establishment code. All policy documents are compiled and are available at universities for reference. Even though policies are available, most academics are not familiar with policy documents.

There are research promotion initiatives such as research units funded by the university, research centers (both self-funded and externally funded), symposia for dissemination of knowledge and training of junior and middle level researchers. In addition, the Committee of Vice-Chancellors, and Directors (CVCD) award schemes are in place to award academic excellence. Furthermore, CTHE (Certificate for Teaching in Higher Education) courses have been introduced to ensure minimum conditions on training for the promotion to the position of senior lecturer.

Apart from the above-mentioned policy initiatives there are research grant schemes available at university level. Collaborative research grant proposals is one such programme.

According to the opinion of the respondents, even though there are policies to promote R&I, a national policy to avoid detrimental ad hoc political decisions is yet to be established. Therefore, it can be concluded that though there are policies to promote research in universities, the status of policy development and implementation based on research evidence is unsatisfactory in the long run. Therefore, a national policy designed to ensure continuity and stability of R&I is required for the sustainability of university research systems and to improve its standards.

4.4 Views on Training and Development Initiatives for R&I in HEIs—Current Context and Gaps

This section highlights findings related to training and development initiatives for R&I in HEIs. The purpose of research-oriented training and development could be two-fold, namely.

(a) to provide training and development of skills and (b) to provide opportunities to undertake research. In order to achieve the first objective of providing training and development skills, the following actions have been taken: (i) training and professionalization by Staff Development Centers, (ii) providing induction training on research & innovative pathways, (iii) enhancing training on scientific writing and research methodologies and (iv) facilitating training activities conducted by Non-Government Organizations such as JAICA, UNISDR etc. targeting individuals who are active in the fields of DR and DM.

With regard to the second objective of providing opportunities for research, research initiatives fall into 3 categories (1) Local research activities (2) Collaborative research activities with foreign universities and (3) International research based on fieldwork in Sri Lanka. According to findings, despite the facilities provided for the development of research skills, researchers have failed to take full advantage of the given opportunities.

4.5 Barriers Related to Research

It is worth noting that it is a challenge for the government to bear the entire cost of research. As a result, there exists an inadequacy of funding for research. Apart from UGC funding and funding from national research and development organizations such as the Council for Agricultural Research Policy (CARP), the National Research Council (NRC) and the National Science Foundation (NSF), no other government institute or agency exists to support research activities by means of funding.

4.6 Inadequacy of Human Resources

Another key aspect that came to light during the interviews was the lack of qualified academic and research staff to carryout R&I within HEIs in Sri Lanka. Most policy makers and top management personnel of universities held the view that universities have sufficient academic and administrative staff to handle the academic load. However, there appears to be a shortage of manpower for the successful completion of research projects. For instance, majority of recipients of NSF grants had failed to submit progress reports on time. These delays appeared to be linked with the lack of qualified research staff.

Research assistants and postgraduate students are recruited for research programmes often on a casual or temporary basis. However, they tend to leave the program/project after finding permanent appointment elsewhere. Therefore, there is no continuity of dedicated research staff. These issues tend to reduce the rigor and the quality of research activities carried out by HEIs.

4.7 Training of Technical Staff

Another factor affecting the quality of research is the inadequacy of training and lack of technical skills in technical staff to handle and maintain lab equipment. In this context, there is a dire need to change and upgrade the recruitment criteria of the supporting staff (commonly termed as non-academic staff) to holders of degrees or equivalent qualifications in order to ensure the proper handling of specific equipment by maintaining both accuracy and safety. It was also highlighted that the lack of opportunities for researchers for professional development is a gap that needs to be addressed.

One of the problems of the university system is that departments and faculties that function as separate entities create very few opportunities for interdisciplinary research. Since R&I in DR demands wider social applications, carrying out interdisciplinary research is critical.

The shortcomings identified above affect the quality and rigor of research. As articulated by a respondent, universities have the highest concentration of qualified staff and there should be policies to facilitate and encourage cutting edge research. In order to promote international collaboration via research, adequate attention needs to be paid to appoint researchers from foreign universities as affiliates, handling visa problems, accommodation, and creating an enabling environment for collaborative research with international participation.

5 Discussion

This study has examined the current context and gaps pertaining to R&I in the field of DM and DR in Sri Lanka. By considering the importance of R&I as a vehicle of knowledge production and by acknowledging the fact that knowledge is the cornerstone of the global knowledge society. What needs to be emphasized based on the findings of the study and in compliance with the advocates of the 'stakeholder concept' (e.g.: Meek & Davies, 2009; Sadana, 2008) is that there is an urgent need to adopt the view that R&I involves the interaction of multiple stakeholders ranging from knowledge producers of other disciplines and knowledge users like government institutions (e.g.: the Disaster Management Centre, National Building Research Organization etc.) and the private sector (e.g.: NGOs and INGOs). Hence, attention must be paid to creating stakeholder awareness on university-based R&I activities and changing the current situation within the university system to promote positive multi-stakeholder attitudes towards and multi-disciplinary involvement in R&I.

Further, corresponding with Kearney's (2009) suggestions for improving the efficacy and strength of R&I in developing countries, the findings of this study reveal that it's pivotal to provide research skills, job opportunities and promote PhD and Postdoctoral programmes among university staff to enhance their research skills and competencies. Lack of trained technical staff has been identified as another gap featuring R&I in the context of Disaster Resilience in Sri Lanka. Thus, taking into account Yutronic's (2007) proposals for enhancing R&I in universities, we recommend that the recruitment criteria for hiring technical staff be defined in a manner that the inflow of technical staff with adequate skills is encouraged. Along the same lines, we point out the need for strengthening/establishing dedicated laboratories for DM and DR related research. Apart from this, administrators and finance staff should be familiarized with the research process and their analytical skills cum knowledge on multidisciplinary research needs should be improved. In this regard, Disaster Management and Resilience needs to be promoted as a specific area of research.

Similarly, Trowler and Wareham (2007) outline seven dimensions of a teaching/research nexus in response to the conflicting role of universities as knowledge providers and knowledge producers. Conforming to this framework and informed by the gaps highlighted in the present study, we harp on the necessity of revising staff time allocations for research, teaching and administrative work in a manner that considerable time and space are provided for R&I activities. Revising staff time allocations for the said activities also call for taking gender differences into account in terms of participation in R&I activities and taking steps to promote gender equality in R&I initiatives. Apart from achieving a teaching/research nexus, we propose the introduction of a permanent research cadre with attractive remuneration packages within the university system so that the costs of a teaching/research nexus outlined by Trowler and Wareham (2007) are minimized to a significant extent.

Sustainability is one of the three critical success factors for research (Ho, 2007). Accordingly, it is plausible to argue that promoting community interaction programs and strengthening technology-based dissemination and innovation are equally important to create an enabling environment to ensure the sustainability of R&I programs in the long run. Moreover, a research screening system with an appropriate criterion should be in place to ensure that research approved for funding has greater potential for innovation. Additionally, promoting linkages with the industry, other relevant agencies and communities is necessary to create innovative platforms to address societal needs through research and improve the pertinence of research, which is another critical success factor for research (2007).

Universities cannot sustain themselves in a competitive environment without R&I elements and attractive packages for research staff and students. Therefore, strengthening/establishing a Research and Innovation arm with the university in collaboration with the private sector as Public Private Partnership programs and awareness raising on existing research grants and related policies should be prioritized. Awareness raising on such grants and policies may encourage research mobility and international collaboration that are major contributors to the efficacy and strength of R&I in universities (Jacob & Meek, 2013).

An absence of a consistent national policy for university research stands contrary to UNESCO's (2005) recommendation for each country to create its own version of a global knowledge society where knowledge production through R&I facilitates the country's national development agenda. While importing knowledge produced in 'the core' appears to be a convenient option, the applicability of such knowledge to the local DM and DR contexts as well as the potential of such knowledge to stimulate locally relevant innovations stand questionable. For instance, most issues that arise in Sri Lanka's DR and DM contexts tend to intersect with endemic variables like caste, subsistence agriculture, rural poverty, and slum culture. Therefore, the need for a national policy that is favorable for university research in the long run, marking national commitment to research, is stronger than ever before. The findings of this study also demand the identification of priority areas that are presently unclear or unrecognized.

6 Conclusion

Disaster Management and resilience building in the context of disasters are paramount for protecting the development gains of specially, developing, and underdeveloped nations where a significant proportion of the global poor reside. This calls for mainstreaming DM and DR into the national development agendas of these countries. However, knowledge production constitutes the mainstay of the global knowledge society and thus, cognitive resources play a critical role in a country's progress towards growth and development. Therefore, the success of DM and DR initiatives in developing nations like Sri Lanka and underdeveloped countries (eg: in the African region) depend on the extent to which such initiatives are fed with timely, rigorous, reliable and locally relevant R&I outcomes. For this, the R&I arm of HEIs in these countries should be strengthened via (1) emulating a multi-stakeholder approach to

R&I, (2) enhancing the research skills base, (3) increasing time and space available for R&I, (4) improving the sustainability and pertinence of R&I, (5) promoting knowledge and technology transfers and (6) fostering national commitment to R&I.

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Role of the Built Environment in Rebuilding Displaced and Host Communities

R. R. J. C. Jayakody, C. Malalgoda, Dilanthi Amaratunga, Richard Haigh, Champika Lasanthi Liyanage, E. Witt, M. Hamza, and Nishara Fernando

Abstract Disaster-induced and conflict-induced forced displacements are among the biggest humanitarian and development challenges of the countries around the world in the twenty-first century. The increasing rate of the forced displacement puts significant pressure on the built environment which popularly includes the challenges associated with delivering the essential goods and services, providing adequate and appropriate housing, and sufficient infrastructure to both host and displaced communities. However, apart from this physical aspect, the built environment has a significant role to play in rebuilding communities addressing the socio-cultural, livelihood, and economic aspects and social cohesion between displaced and host communities. The understanding of this complex and multifaceted role of the built environment is an essential factor in resettlement planning in order to deliver a successful relocation program ensuring the long-term satisfaction of the displaced and host communities. With the identification of this research need, the project titled REGARD (REbuildinG AfteR Displacement) which is a European Commission funded collaborative research project, investigated the role of the built environment in rebuilding communities following the disaster and conflict-induced mass displacements. The method involved first reviewing the literature related to the field and conceptualising a framework based on literature synthesis. Data collection was initiated through the selection of participants using purposive sampling which include government officials, community representatives, social support networks, agency networks. A total of 37 interviews were carried out by the 3 partner countries; 12 in the UK, 11 in Sweden,

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and 14 in Estonia. In the context of Sri Lanka, 10 key informant interviews and focus group discussions with community members were conducted covering both conflict-induced and disaster-induced displacement. Analysis revealed that the built environment has an instrumental role to play in rebuilding displaced and host communities by acting across six perspectives; constructing physical assets, stimulating economic assets, facilitating institutional assets, developing human capital assets, nurturing social assets, and protecting natural assets. This chapter presents the research findings across these six perspectives synthesising the role of the built environment (BE) in rebuilding communities and enhancing social cohesion between host and displaced communities. Finally, the chapter introduces a comprehensive framework of role of the built environment, summarising the research findings which can be used by the future academics, practitioners, and policymakers in the field of displacement resettlement planning.

Keywords Built environment · Conflict-induced displacements · Disaster-induced displacements · Rebuilding communities · Social Cohesion

1 Introduction

The phenomenal rate at which people are being forcefully displaced on a daily basis puts significant challenges on the development of countries all over the world. The recent record of UNHCR (United Nations High Commissioner for Refugees) on global forced displacement alone shows that by the end of 2016, 65.6 million were displaced, and by the end of 2019, it rose to 79.5 million (UNHCR).

There are four main causes of displacement; environmental-induced displacement, development-induced displacement, disaster-induced displacement, and conflict-induced displacement (Terminski, 2011). Out of these various causes of displacement, disaster-induced displacement and conflict-induced displacement take over a greater percentage of the total number of people displaced globally, thereby contributing to make displacement a global challenge. The EU witnessed the climax of this challenge in 2015, more than one million refugees and migrants arrived in Europe, about half of whom were fleeing the civil war in Syria and about one-third of whom were seeking political asylum (Greenhill, 2016). Moreover, the Nansen Initiative record shows that between 2008 and 2014 unexpected onset of disasters displaced a total of 184.4 million people (The Nansen Initiative, 2015). Internal Displacement Monitoring Centre (IDMC) highlights that the Philippines and China have the largest amount of internal displacement due to disasters, with each having 3.8 million newly displaced in 2018, followed by India (2.7 million), and the United States (1.2 million). These figures confirm that disaster-induced and conflict-induced displacement are among the biggest humanitarian and development challenges across the world. With this view, in this chapter, the emphasis will be laid on conflicts and disasters induced displacement.

In a forced displacement situation where people are forced to flee from their homes, will be mostly introduced to a new built environment both in short-term and long-term resettlement plans. The built environment is the environment that varies from somebody's bedroom to the entire layout of the neighborhood and every scale in between which is an integral part of the daily lifestyle of the inhabitants (Heer, 2018). Accordingly, the built environment where the displaced are introduced to includes houses for accommodation, schools, hospitals, playgrounds, public spaces, open spaces, green areas, and well-built street layouts. Each of these features influence the daily lifestyle of the displaced.

Apart from that, the sudden influx of displaced communities and the changes in the built environment will influence the host communities and host governments who receive the displaced. Especially, concerning the host communities, if the impact of the new arrivals is positive the relationship will be positive between the two communities which can be named as social cohesion. However, if the impact is negative the relationship will also be negative. If the arrival of displaced communities is posing substantial pressure on the built environment, this becomes a significant threat to the social cohesion between the host communities and displaced communities.

The forced displacement changes social relationships; it is frequently associated with social disruption, tension, grievance, social fragmentation, and economic upheaval (World Bank Group, 2018). Within this context, the development of a built environment can be conceptualized and planned to identify and meet the social and economic needs of the people and enhance both the social resources and the strengths of residents and users, as well as benefiting the local economy (Baldwin & King, 2017). This emphasizes that even in the displacement context the role of the built environment is not limited to shelter, housing, and infrastructure provision, it is supposed to meet diverse needs of displaced, including social needs, economic needs of the people while enhancing the social cohesion between displaced and host communities. However, in most of the recovery and resettlement programs, the emphasis has given on the physical aspect of the built environment with a lack of consideration on meeting the diverse needs of the displaced and social cohesion between the displaced and host. Moreover, the understanding of the resettlement planners on the complex role of the built environment decides the success of the resettlement programs. Recognizing this research need, this chapter explores this multifaced role of the built environment which contributes to the long-term satisfaction of the displaced and the social cohesion between displaced and host communities.

2 Built Environment in the Context of Displacement

The built environment is generally defined as the part of the physical environment that is constructed by human activity (Forrest & Kearns, 2001) and the quality level of the built environment will have a direct impact on the social activities and behavior patterns especially in urban settings (Nicola Dempsey, 2008). The vital role of the built environment to the surrounding society can comprehensively described based on four inter-related aspects (Bartuska & Young, 2007). First, it is widespread and delivers the context for all human activities. Everything included in the built environment is humanly created, modified, or constructed, humanly made, arranged, or maintained. Second, it is a creation of human minds to fulfill human needs, wants, and values. Third, it is shaped to assist the inhabitants to deal with, and to protect and facilitate for improved comfort and well-being. Finally, is that every component of the built environment is defined and shaped by context and all of the individual elements have a positive or negative impact on the overall quality of the built environment.

According to Haigh and Amaratunga (2011), the ability of the built environment to contribute to societal resilience will be along the basic roles of the construct, develop, stimulate, facilitate, protect and nurture. If these six basic roles are adopted to the displacement context, one of the main roles of the built environment will be to construct or provide the physical assets for the communities. Several scholars have argued that shelter or housing is an essential part of the recovery and resettlement procedure for the displaced and its reconstruction is linked to social and economic recovery of the community (Haigh et al., 2016; Jordan et al., 2015). According to Barakat (2003) housing is essential to the well-being and development of societies because it is a complex asset, that has links to livelihoods, health, education, security and social and family stability and acts as a social center for family and friends, a source of pride and cultural identity, a resource which commands both political and economic importance. Accordingly, housing becomes an extremely vulnerable asset, that the destruction or loss of homes through displacement (Barakat, 2003) is among the most evident effects of conflict and natural disaster.

The next role of the built environment is to develop for example in terms of social infrastructure and capacity development. The Build Back Better as narrated by Lamond et al. (2013) is a phrase that was developed as a recovery effort following the 2004 Indian Ocean Tsunami. That it represents an ideal and holistic approach to reconstruction as a measure to recover the physical, economic and social conditions of the built environment beyond its pre-disaster stage. The goal is to ensure that the displaced enjoys a much better built environment than what was destroyed by conflicts and disaster, and this can have a significant impact in enhancing social cohesion between the displaced and their hosts (Lamond et al., 2013).

Another area in which the built environment has a role to play is in stimulating the development activities which bring economic benefits and opportunities to both displaced and host. This could be implemented via governmental and institutional initiatives or community-based initiatives such as livelihood assistant programs and initiatives for economic independence of displaced. The role of the built environment will be to provide or facilitate a ground for the people to come together and interact despite the variations and diversities through institutional arrangement and procedural matters (Baldwin & King, 2017).

The built environment and the way how it is planned and developed is a dominant paradigm of urban sustainability and environmental protection. According to Bergman (2018), by creating carefully styled living environments through planning and design, people's lives are positively influenced and important for safeguarding the natural ecological systems and to promote sustainable development so that the future disaster risk could be mitigated.

The nurturing role of the built environment will include social interaction and networking, safety, and social equity for disabled, aged, women, children. A framework for creating nurturing environments developed by Komro et al. (2011) includes a sperate section relating to the built environment as a physical environment and explains the nurturing role through neighbourhood design, land use, and housing. Bergman (2018) demonstrates that the built environment is important in the construction of social cohesion, that without a well-constructed built environment and adequate provision of these houses, social cohesion cannot be achieved.

Based on the above discussion it is evident that the built environment has to play a significant role in rebuilding communities and establishing the social cohesion between the displaced and host communities. Accordingly, in investigating the role of the built environment within the study the following methodological approach is used.

3 Methodology

The work presented in this chapter is based on the part of the findings of the project titled REGARD (REbuildinG AfteR Displacement) which is a European commission funded project, aims to develop competencies in rebuilding communities following a disaster and conflict-induced mass displacements from the perspective of the built environment. This chapter is a part of the outcome of a comprehensive research process that started from conducting a countrywide need assessment on disaster and conflict-induced displacement and relocation in the four participating countries namely, the United Kingdom, Sweden, Estonia, and Sri Lanka.

The second objective of the project is to identify the role of the built environment in addressing these identified needs and to enhance the social cohesion between the displaced and the host. In achieving is the second objective, a comprehensive literature analysis was conducted to define the core concepts; displaced and host communities, social cohesion and to explore the existing literature on the role of the built environment in enhancing social cohesion. Based on the literature findings and the initial findings of the community need analysis, the research instruments were developed to collect primary data. Primary data were collected from four partner countries; Sri Lanka, United Kingdom, Estonia, and Sweden through interviews and focused group discussions.

3.1 Displacement Contexts in Four Partner Countries

The UK became a country of immigration from the mid-1980s even though it has received immigrants for centuries (DEMIG, 2015 citing MPI, 2009; Somerville et al., 2009). Currently, according to the immigration statistics (UK Home Office, 2019), there was a steady rise in the total asylum applications in the UK from 17,916 in 2010 to 39,968 in 2015. Followed by a slight fall of a few hundred in 2016 to 39,357 and an even greater fall to 34,435 in 2017. However, 2018 witnessed another increase in asylum seekers' application to 37,453. Hence, the in-flow of asylum seekers has been on the increase in the UK within the past decade.

Sweden has seen a relatively stable immigration of displaced (as measured by asylum applications) over the last 30 years. Between 1992 and 1993, there was an increase in immigration showing large populations from Bosnia-Herzegovina, Serbia, and Montenegro (Swedish Migration Agency, n.d.-a) and the latter 2014–2015 the increase being largely from Syria, Iraq, and Afghanistan (Swedish Migration Agency, n.d.-b).

Displaced persons in Estonia are small in number both in absolute terms and concerning the size of the Estonian host population. According to Eurostat database information, both the number of asylum applications (per capita) in Estonia and the rate at which asylum applications are processed have been considerably below European averages for the years 2009–2018. According to government statistics, Estonia has granted protection to 445 people in the period 1997–2017. 217 of these have been granted refugee status and 228 subsidiary protection status (Valitsus.ee, 2019).

Displacement in Sri Lanka is generally caused by three factors namely disaster-induced, conflict-induced and development-induced. Since this project studies, both aspects of relocation two areas that are Kilinochchi in the north (conflict-induced) and Kegalle in the central (disaster-induced, landslides) have been selected as the study locations. During the last two decades of the Sri Lankan history, the 26-year long conflict between the Liberation Tigers of Tamil Eelam (LTTE) and the Sri Lankan armed forces have made more than 73,700 people displaced in the country's Northern and Eastern Provinces (Fernando, 2009). Together with, as at 31st of December 2018, 258,412 families consisting of 883,185 displaced persons have been resettled in the Northern and Eastern Provinces (Ministry of National Policies, 2018).

3.2 Data Collection

In the European context; UK, Sweden, and Estonia, primary data collection was carried out using semi-structured interviews where participants are required to respond to open-ended questions to examine how they subjectively interpret the phenomena in question and to allow them to expand on the information provided. Participants are recruited using purposive sampling focusing on government officials, community representatives, social support networks, agency networks. A total of 37 interviews were carried out by the 3 partners; 12 by the UK, 11 by Sweden, and 14 by Estonia.

The methodology employed by Sri Lanka for primary data gathering is slightly different from the European context. This is because its focus is on internally displaced communities whereas the European context is more Refugees and asylum seekers. Data collection was done separately with respect to the two kinds of internal displacement in Sri Lanka; that is, (1) the conflict-Induced displacement; and (2) the disaster-induced displacement. For the Sri Lankan primary data collection, multiple cases of displacement locations existing within the country were explored and screened to identify cases that are more suitable within the REGARD scope of work. Accordingly, from the Sri Lankan context, two settlements of Malayalapuram and Bharathipuram belonging to the Kilinochchi were selected for the Conflict-Induced displacement following the initial exploration and screening of multiple cases of displacement done earlier; but for the disaster-induced displacement, all the districts affected by the 2018 flooding and landslides were considered as research locations. Accordingly, covering the disaster induced displacement a focused group discussions were conduced with 10 community members. Apart from that key informant interviews were conducted with 5 officials. Covering the conflict induced displacement focused group discussions were conducted with 10 community members (5 each from the two locations). Key informant interviews were then conducted with 4 officials related to the field.

3.3 Data Analysis

For the data analysis, a methodological framework illustrated in Fig. 1 was developed through a brainstorming session with the participation of all the project partners of the REGARD Project. This methodological framework was developed adopting and combining the role of the Built Environment Framework (Haigh & Amaratunga, 2011) and the 'Do No Harm' Relationship Framework (Wallace, 2015). This is an innovative approach that can be used by future researchers in the built environment and resettlement fields.

Role of BE in Addressing Community Needs and Social Cohesion	Context	Intervention	Dividers & Connectors	BE Related Options	Who is Responsible (Stakeholder)	Which stage
Construct – Physical Assets/Interventions						
Develop – Human Capita Assets/Interventions						
Stimulate – Economic Assets/Interventions						
Facilitate – Governance Assets/Interventions						
Protect – Environment Assets/Interventions						
Nurture - Social Assets/Interventions						

Fig. 1 Methodological framework used for the data analysis

Once the methodological framework (Fig. 1) is developed and agreed by the project partners, the literature findings and primary data were mapped to the methodological framework. The findings were then validated through the focused group discussion which was conducted with the participation of 14 experts and practitioners in the fields of resettlement planning and resilience. Finally, the research findings are presented in Sect. 4 identifying the role of the built environment in addressing community needs and to enhance the social cohesion between the displaced and the host communities.

4 Findings; The Role of the Built Environment

Findings suggest that the built environment has an important role to play in rebuilding displaced and host communities and enhancing the social cohesion by acting across six perspectives; constructing physical assets, stimulating economic assets, facilitating institutional assets, developing human capital assets, nurturing social assets, and protecting natural assets. Accordingly, in this section, the findings are presented based on these six perspectives.

4.1 Construct: Physical Assets

One of the main roles of the built environment in rebuilding communities is to construct or provide the physical assets for the displaced communities. In the displacement when it says physical assets, the most popular asset is the housing provision. Two most highlighting grounds of the housing provision for displaced communities are adequacy and quality.

In the context of the United Kingdom, there are two main channels of becoming a refugee; the Asylum Channeled Refugees (ACRs) and Resettlement Channeled Refugees (RCRs). The housing that comes with the resettlement scheme package is in good condition. However, refugees who came through ACRs and who cannot find accommodation by themselves are dispersed across the country with a no-choice basis. Therefore, the housing conditions depend on where the ASRs have been dispersed to live.

In the context of Sweden, Accommodation provided by the Migration Agency is on a no-choice basis. The quality of agency provided housing varies. In the context of Estonia, the general shortage of social housing was confirmed in the interviews and that this was a factor in the initial strategy of dispersing displaced people throughout Estonia.

While the housing issues related to adequacy and quality exist in the European context, the data collected in Sri Lanka revealed that especially in the conflict-induced displacement cases, some people are still living in temporary housing with no proper cover for protection from water during the monsoon season. This results in most people get affected by illnesses. Therefore, adequate initial temporary housing and allocated period is also an important factor to be considered in resettlement planning. Another problem related to housing in some cases in Sri Lanka is that sometimes more than one family is living in one house as those who have children who are married also live with their parents due to the lack of adequacy of housing provision. Likewise, the issues related to adequacy and quality exist in countries in different levels depending on the context.

Commonly, refugees and asylum seekers who gain access to housing are mostly restricted by affordability especially in cities. This leaves them no choice but to the likelihood of poor housing conditions. Therefore, adequate provision of affordable, standard, and quality housing for displaced is identified as a foremost need and essential role related physical assets of the built environment.

The second factor related to the housing provision is the decision over the location of resettlement housing. In some cases, the location of resettlement housing does not match with the social, cultural, and economic needs of displaced communities. For instance, in the UK, everyone has a right to worship. But study suggests that religion does not seem to be considered when dispersing the displaced people to their respective houses. For instance, lack of religious places in some areas would pose a problem to displaced if they are dispersed into accommodation in such areas. Some of the respondents mentioned that if their denomination is not near, they are ready to travel miles to attend their religious place e.g. mosques, churches. In Sweden, which municipality the refugee is allocated to is determined, based on the municipality's size, the local labor market situation and the number of refugees and newly arrived already living in the municipality, in combination with the specific needs of the refugee. However, the newly arrived resident normally has a little say in where he or she will be settling.

Another example from the case studies in Sri Lanka, social tension arose since the houses were built on a cemetery without the officials taking necessary steps to conduct cultural purification rituals and this has a huge impact on their cultural needs. Therefore, it was identified that the location of housing needs to be matched with social, cultural, economic needs, and land-use patterns of the areas.

The next factor is related to the size, layout, and design of resettlement housing. In the UK context, it was identified that the size of housing allocated to the RCRs is dependent on the size of the family as informed by the UNCHR who have made a comprehensive assessment of the potential refugee family and everything that pertains to them. However, in the case of ACRs, some agree that the size of housing is commensurate to the size of the family. But some respondents argue that there is a cookie-cutter approach to housing whereby size, age, and disability demography of families are not addressed. In the context of Estonia, one of the major challenges in terms of finding housing is the size of displaced people's families which tends to be much larger (up to 7 children) than local, Estonian families (usually 1 to 3 children) and this is reflected in the housing stock and therefore it is difficult to match the size of the family with the existing housing stock.

Apart from the size, the layout and the design are also an important factor to consider. For instance, in the Sri Lankan case study, respondents complained about the architectural design of the house with respect to ventilation, lack of garden to dump their garbage, problems of sanitation as the washroom is built inside houses. Some of the respondents prefer having it outside since the two rooms inside the house are attached to the bathroom which does not match with their way of living. Further, the kitchen is designed for use of gas cookers whereas, most of the respondents have been using firewood for cooking purposes and they are reluctant to switch to gas cookers due to the lack of understanding of how to use such appliances which creates a security issue and the inability to spend a considerable amount of money on gas as the firewood is freely available from the woods. Considering these facts, it was identified the need of matching the size, layout, and design of resettlement housing with the social, cultural, and economic needs of displaced communities.

The above discussion under the physical assets is mainly focused on the housing provision. The physical assets also include the provision of basic services and infrastructure facilities. This includes the provision of safe drinking water and sanitary facilities, electricity, education and healthcare facilities, and transport infrastructure (Roads, Bridges, public transportation). The provision of basic services and facilities is an essential and important factor due to two main reasons.

Firstly, these basic services and facilities cover the basic needs of people such as education, healthcare, and transportation. Therefore, lack of provision can result in many other issues such as health issues, lack of employment and poverty, and social tension. For instance, the case examples in Sri Lanka demonstrate that lack of and poor access to available health facilities and lack of basic health knowledge lead teenage/unmarried pregnancies, illegal abortions, and mental health problems among communities. With regard to hospitals, the respondents relocated from disaster-induced displacement acknowledged that they can reach the city hospital in 20 min. However, they believed it would have been better if there was at least a dispensary in close proximity to the settlement as it would be useful during emergencies. Further, lack of public transportation services and internal road conditions were considered as the main reason behind the decisions of people returning to their original housing from the relocated housing. The condition of the internal roads was also reported to have affected respondents returning to their places of origin concerning the additional costs borne for transporting construction material.

Secondly, the provision of adequate basic services and facilities is important since the sharing host communities' access to basic services and facilities, may erode their capacity which results in tension between displaced and host. Further, equal provision of basic services and facilities indicates the social equity and inclusion. When displaced communities are faced with a combination of linked problems such as unemployment, poor housing, poor skills, low incomes, bad health, lead to their being excluded from the outcomes and opportunities enjoyed by the mainstream society (Firm Foundations 2004). Hence, adequate and equal provision of basic services and infrastructure facilities to both displaced and host is an important factor contributing to social cohesion between the host and displaced.

The provision of public places and play areas is correspondingly an important physical intervention contributing to the wellbeing of displaced communities.

Conversely, lack of open spaces and play areas affects the physical health and physiological wellbeing negatively. There are reports of the displaced persons claiming that they enjoy the visits organized for them in the parks and those who make use of public places like the library, gym, playgrounds, and community gardens enjoy them and make them happy. Besides, respondents proved that density, lack of green and play areas are aspects of the built environment that influences children's wellbeing. Further, the study confirms that once the provisions are made it is also important there are no restrictions to get access to these places. Therefore, relocation programs need to consider both physical and visual access to public places, open areas, and play areas that positively influence the wellbeing of displaced.

4.2 Stimulate: Economic Assets

The next important role of the built environment is to stimulate the economic assets. Within the displacement context, financial aids, support, and assistance are considered as the most popular interventions concerning the economic aspect. However, the study informs that when the financial aid and support are given the displaced become reliant of this support and will become a burden to host government and the economies. Therefore, with a long-term perspective, it is important to create employment and economic opportunities aiming for the financial independence of displaced communities. Demonstrating an example, in the UK there seems to be little provision by the government specifically for vocational studies for the refugees and asylum seekers. This is one of the needs which would help them to become self-reliant and also help them gain employment so they can be financially able, thereby taking off some financial burden of support from the government. However, three respondents claim that vocational training like NVQs; training in different skills, for example, sewing, car mechanics, and so on are generally available to the refugees as with any other UK citizen. Some voluntary organization arrange such certified courses such as food hygiene, safeguarding, health and safety at work, from time to time for those who can understand the English language to help them get self-reliant.

Opportunities for self-employment is reported as one of the fastest avenues mentioned whereby the refugees gain access to the labour market in the UK. There are opportunities on the ground for refugees with realistic business plans that require an understanding of the economic and social networks that exist within their chosen trades are assisted to set up their own businesses and granted some interest-free loans. In the context of Estonia, self-employment is a possibility and there are examples of refugee-led enterprises in the catering industry in Tallinn and Tartu. There are no restrictions in terms of owning or managing businesses and have equal access to self-employment. There are support programs in place to encourage employers to employ displaced people such as the "My First Job in Estonia" which provides regular support and subsidizes the wages of employees who are beneficiaries of international protection and also the Diversity Charter. Likewise, creating employment and economic opportunities aiming for the financial independence of displaced communities is identified as an important factor that should be created and facilitated by the built environment.

Another aspect of the financial independence of the displaced is ensuring the economic stability of communities with special needs including women, aged people, and disabled people, etc. For instance, in the case of displaced women, those who look after children would also need help to find and access childcare so that they can also seek employment. Study confirms that childcare is a major need for refugee and asylum seeker women. It stands as a barrier to their attending the language classes because they have children to take care of. The inability to speak and write the host communities' language eventually limit their access to employment. Considering the economic independence of disabled people or aged people especially who are with less mobility, provisions promoting home-based self-employment can ensure economic stability. Likewise, the built environment should facilitate the financial independence of the displaced ensuring the economic stability of communities with special needs.

Access to previous livelihood or place is also identified as a vital role within resettlement planning especially when the land/place is attached to livelihood and identity. In the Sri Lankan context, agricultural livelihoods are the most vulnerable livelihood to be affected due to relocation. The impact on livelihood is severe after displacement as IDPs are being forced to leave their livelihood behind which causes the loss of income. Their arrival in host areas also have consequences for local labor markets, disrupting wage levels and increasing unemployment rates and the need for social protection. This economic instability can cause threats to the wellbeing of both communities due to their inability of sustaining a position in the labour market (International Displacement Monitoring Centre, 2018). Therefore, in such instances, through the built environment interventions, it is influential to provide access to previous livelihood wherever possible. In such cases, provision of housing proximity to the previous livelihood, increase the road and transportation connectivity between the resettled houses and place of livelihood, housing layout design facilitating the livelihood activities are some of the recommended interventions from the built environment perspective.

Housing provisions were already discussed under the physical assets. However, through the data analysis affordability factor of housing need to be considered as a factor which stimulates the economic assets. In the context of the UK, some of the respondents acclaim that the social housing provided by the local authorities through council houses and housing associations are affordable as asylum seekers and refugees are dispersed into areas with inexpensive rent. It has been found that affordability is an element to be considered in the choice of housing with RCRs because there is a certain budget for housing sourced for them, hence they do not go for expensive housing that would not be covered by the available budget. However, there are very few affordable housings in some areas or none. One of them argued that the lack of affordable housing is due to the government's capping of housing benefit. Hence, they tend to lodge in other people's houses as lodgers or find shared housing where they can put their housing benefits together to make enough for housing cost, thereby resulting in overcrowding, and lack of privacy. But for the RCRs, in cases like this, the home office pays what is referred to as a top-up. And those who cannot find any of these might end up becoming destitute. This confirms the assertion in the literature review that the 28 days given to asylum refugees to vacate their initially allocated houses has resulted in a lot of refugees becoming destitute. Therefore, housing benefits need to be guided by the current market demand to make sure the housing benefits are enough to access to affordable housing.

In Sweden, for economic reasons are forced to choose housing in certain districts, illegal contracts, third-hand contracts, overcrowding of apartments, and non-favorable lodging agreements (inneboende in Swedish). The strain put on the Swedish welfare system because of the uncontrolled movements of people was also mentioned. Displaced who find their own housing often necessary to move outside of the big cities due to the affordability, which may pose a problem when they have become rooted and built up a social network. Therefore, it is important to increase the availability of affordable housing through the collaboration of public–private partnerships. As an example, a municipality in Sweden launched a very successful housing project funded by the government where it collaborates with organizations in the countryside to place refugees in houses without tenants or owners in the countryside. The municipality mediates between the refugees and the organization providing the housing and this has assisted close to 400 people in getting housing within two years. Likewise, collaboration, partnership, and availability of many housing options as per the different requirements of the displaced ensure the affordable housing providers such as social housing, housing provided by community support organizations, public–private partnerships, voluntary organizations (Vos), or NGOs and so on.

4.3 Facilitate: Institutional Assets

In order to facilitate the institutional assets, four types of interventions have been identified from the perspective of the built environment. The first intervention is the provision of improved support on services, advice, and activities aimed at local integration and assistance. The integration of newly arrived refugees to the local context is an important factor to consider in resettlement planning. Provision of housing, basic services and facilities solely cannot integrate the new arrivals to the local conditions. Provision of the right direction to the refugees and asylum seekers to find necessary services, supports available within the local context will also ensure smooth integration. For instance, the Estonian refugee council provides beneficiaries of international protection with support services, advice, and activities aimed at integration and assistance. Support services are primarily delivered through support persons who help beneficiaries to understand and navigate the systems in Estonia and become self-sufficient as quickly as possible.

The involvement of civil society in the integration process was also emphasized repeatedly throughout interviews with the Sweden municipalities as well as NGO representatives. Both municipality and NGO representatives wished for more systematic and organized cooperation than is currently the case, and as was the case during the big refugee movements in 2015 and 2016. This crisis showed the need for involving civil society, and the importance of civil society initiatives should not be underestimated by the municipalities. One municipality representative mentioned that more money must be given to community organisations such as the Red Cross in Denmark, for them to help more with integration. The representative meant that such organisations should be able to get remuneration from the state to perform certain integration tasks. Alike, it is important to empower and promote the activities of the community groups to get the involvement of the civil society and social networks to perform certain integration tasks. Further, municipalities or local authorities can collaborate with NGOs or community organizations to provide quality and continued services and activities aimed at local integration.

The second intervention is the provision of adequate information, time, resources, and technical guidance for local authorities and implementation bodies. Research findings show that in some countries local councils are not prepared for arriving refugees, hence the refugees find difficulties. Whilst some countries (e.g. Sweden) as per the regulatory measures (e.g. Bosättningslagen) the municipality knows who and how many refugees are arriving, and hence may plan and prepare for local integration accordingly.

Adequate information, time to prepare, and working along long-term perspectives were mentioned by many representatives as keys for successful integration, especially in the initial reception of refugees to the municipalities. Some representatives also hinted at the inadequacy of the information received—for some representatives, it seemed that all information they would receive was the refugees' name and birth-date, without any further information as to the refugees' background and specific experiences. On the other hand, the inherent leeway of Bosättningslagen described above gives the municipalities opportunities for structuring the reception of refugees according to local conditions.

Third Intervention is to improve the government strategies and enhance the legal and policy framework of relevant authorities for creating and building inclusive societies for displaced. All four contexts of the study (UK, Sweden, Sri Lanka, and Estonia) shows that there are needs to improve the government policies and need to structure the investment accordingly for creating and building inclusive societies for Displaced. In the UK, it was highlighted with literature and confirmed by the data that the government policies are contriving a two-tier refugee protection system in which the RCRs are well provided for while their ACRs counterparts are left with little support, thereby damaging their prospects of integration. Therefore, government strategies need to increase both the benefit rates and the social housing stock to make sure the provisions are for all the displaced persons' categories, that is, RCRs, ACRs, and the AS.

In Sweden, both the municipality and NGO representatives mentioned that how the Swedish government strategies are inadequate "putting out fires" strategies that are arbitrary and short term in character. It was also mentioned that inadequacies of the Swedish refugee reception strategies and policies. In Estonia, there appears to be considerable overlap in the remits and service provision by the different organizations. There appears to be considerable overlap in the remits and service provision by the different organizations, so there is scope for the refugee services to be greatly rationalized for more efficiency and better service delivery. This need for better integration has been raised in various contexts, e.g. (UNHCR, 2016) for the provision of support persons by different organizations. In Sri Lanka it was highlighted that, there is no single authority responsible to address multiple issues pertaining particularly to victims of displacement (Fernando & Punchchihewa, 2013). Therefore, there is a need of designing a systematic framework that can incorporate all aspects of relocation within a legal frame.

The fourth intervention is to maximize the stakeholder engagement in resettlement planning including displaced and host community's engagement as well as the host local council/ municipalities' engagement. Firstly, the community engagement of both displaced and host is important to understand the needs and aspirations of the community within the resettlement planning. In one municipality in Sweden, each individual is invited for a conversation, where the topic is not economics, maintenance support, or the like (i.e. a conversation which does not focus on the refugee's obligations towards its host society). The individual is asked to talk about for example, what he or she thinks characterizes integration, what his or her current needs are, and what dreams and aspirations he or she has for the future. The municipality started with this type of conversation in 2015 and the representative thinks it has had a good effect on integration in the municipality. However, this type of approach may not be practical in a mass displacement situation. In such cases, the involvement of the community representatives, voluntary organizations are also important within the stakeholder engagement.

Apart from that, research findings pointed out that the resettlement plans which are prepared by the national government sometimes do not take into account the specific needs of local councils/municipalities. Sweden, e. g. Migration Agency does not take the host municipality into account in the planning of its asylum centers. Therefore, placement of asylum reception centers and the inflow of new inhabitants that come with them disturb the municipality welfare system. Therefore, matching to the individual context it is important to develop a mechanism to engage all the relevant stakeholders including displaced, hos community, host local council/ municipalities when preparing the resettlement plan.

4.4 Nurture: Social Assets

In resettlement planning, the built environment has a dynamic role in addressing the social needs and enhancing the social cohesion between the displaced and host communities. Research findings revealed that in countries such as the UK if the displaced cannot find their own housing and when other related organizations do not help to find accommodation, the last choice is that displaced are dispersed within the country with no choice basis. However, this method has led to many social and economic issues. Dispersed displaced are housed in deprived areas with multiple problems and little or no experience of diverse communities; leading to social tension and racism towards the displaced. When the people are dispersed within the country wherever housing is available, sometimes refugees are sent to areas where refugee community groups are less developed. This adversely affects the integration: leading to social tension and racism towards the refugees. As an example, this study revealed the existence of cases of antisocial behaviour that are more popular in some British communities than in communities that are more diverse like Preston. One respondent says displaced persons are bothered by some host communities and some landlords would not want to rent their houses to the refugees as well. In contrast, refugees in areas with diversity, social inclusion is much easier because the city is large and public services and spaces abound where one can go for organization and make new friends. It is also easier for those who have people from their cultural backgrounds around them. They can meet for social events like marriages and birthdays where their culture in terms of language, food, and fashion is being showcased.

Correspondingly, in the Estonian context, this policy of dispersion was later found to be a mistake as it placed resettled people in suboptimal locations, led to their relative isolation, and made integration activities and services much more difficult to organization. Subsequently, newly arrived asylum seekers and refugees have been accommodated at the reception centers in Vao and Vägeva for some months first before being assisted to find more permanent accommodation according to their own needs and preferences and, typically, in the more populated urban centers of Tallinn and Tartu, Estonia. Therefore, the research findings suggest that it is vital to relocate the displaced communities to suitable and welcoming neighborhoods who have experienced diverse communities or refugee/displaced community groups are more developed. Through this intervention, it is easier to make the social inclusion and local integration which can increase the sense of belonging and mental health of displaced.

Apart from relocating to welcoming suitable neighborhoods, social integration can be promoted through the way the built environment is planned and designed. For instance, the built environment can be arranged to often get together and participate in activities, with more public, cultural and religious places. Some events are being organization by the county, local authorities or charity organisations such as trips to other areas of the country, a walk in the parks, football groups, drama presentation by the displaced and the locals. As an example, in the UK, there are loads of public events that are organization by voluntary organisations and church groups, to expose the displaced together with their host community to organization and make new friends, thereby enhancing their engagement and integration with their local community. Examples of such events are the Refugee week, the Women's Lunch Club where they socialize, and even learn new trades such as sewing. Further, these interventions need to be operated in all scales; neighbourhood/ local and regional.

Nevertheless, these social integrations focused on built environment interventions need to be carefully evaluated to match with the context, especially when the host and displaced come together with different social, cultural, religious, language backgrounds. For example, community representatives in Sweden mentioned that the groups who arrived have different social patterns than the host community, in the sense that they move around outside a lot more; occupying the town square in small groups, and their children also play and move around outside a lot. The representative further explained that this differs from the social norms of the host (Sweden) community, and this has sometimes been a cause for concern. For example, women feeling insecure walking across the town square because of groups of immigrant men. According to the representative, to meet the social needs of the newly arrived groups more public places are needed, such as small cafes or hair salons where they can hang out with each other instead of the activities officially organization by the municipality which in the representative's perception, the new groups do not have enough spare time to join in.

The research findings revealed that the built environment also can increase the sense of belonging and attachment to the community of both host and displaced. An individual's lifestyle is, the way one lives and copes with the physical, social, economic, psychological environments daily which is reflected in daily activities, values, interests, attitudes, opinions and at home, work or leisure, and influenced by family, culture and social class. The Built Environment is the space, which comprises structures, facilities, and resources that accommodates and permits all of these for the individual. The way a community's built environment is designed influences the physical and mental health of its residents (Dannenberg et al., 2018; Frumkin, 2016). A community's wellbeing can be improved by the local characteristics of buildings and neighbourhoods as they increase the sense of belonging and attachment to the community (Janahi et al., 2018; Burton, 2014). However, these improvements to the local characteristics of buildings and neighbourhoods should also preserve the local identity of the host promoting social cohesion.

Maintain the social equity in services and housing provision is another important aspect contributing to the social cohesion. Especially concerned with housing, it was found that sometimes the provisions are not fair and identical for all the types of displaced. Governments should identify housing as an important aspect of the integration process. Hence, the relevant institutions should make available to the asylum seekers and refugees' access to safe, secure, and affordable housing.

The provision of easy access to social services and support for the displaced is another important intervention within the built environment. There are vulnerable individual and families within displaced who needs extra support from social services. Social Services support families and safeguard children who may be at risk of harm. Social services include the benefits and facilities like education, food subsidies, health care, police, fire service, job training and subsidized housing, adoption, community management. Sometimes, access to social services and support as well as information about these is closely tied to language proficiency of the host country e.g. Estonia. Therefore, there it is important to organization a needs assessment by social services through the local council/municipalities to support displaced who need special support with facilities such as, home care help, disability equipment, daycare centers, care homes, and language training, etc. Further, in some cases displaced are not aware of accessible social services because of problems in coordinating numerous different support persons from different agencies and NGOs without clear role definitions. In such an instance, it is also vital to create an organizational network in collaboration with local authorities and define the clear roles of these organisations.

Another important aspect of nurturing the social asset is the provision of easy Access for emotional support and mental healthcare provisions for the displaced. Most of the displaced people have suffered and are still suffering from the trauma of whatever made them flee or leave their habitual place of residence. Hence, they battle with different mental issues. Further, there are difficulties in adapting to the new culture might cause mental health problems, such as depression. Further, the research findings revealed in most of the contexts, there are little or no provisions for mental health and emotional support especially focused on displaced. Demonstrating a best practice, in the UK, having received prior information concerning all aspects of the life of the RCRs from the UNHCR, upon their arrival, they would be assessed on their health, wellbeing and mental health and if there is need, they would be referred for treatment. Mental healthcare such as common anxiety disorder treatments and cognitive behavioural therapies are available for the RCRs and it is well funded. Nevertheless, some barriers such as language and issues with interpreters as mentioned earlier impede this access. There exists also primary and secondary mental healthcare support in the UK. Likewise, the availability of these services, physical access as well as procedural access to these mental health and emotional support also an important aspect in the displacement context.

4.5 Develop: Human Capital Assets

Human capital refers to the habits, knowledge, skills, personal attributes, and capacities that directly and indirectly contribute to produce an economic value. The research findings suggest that the built environment has a role to play in developing this human capital within resettlement planning. In doing so, one of the interventions is the provision of adequate and equal access to education for displaced same as the host. In countries such as the UK and Estonia, that children gain access to primary and secondary education quickly as attested to by most of the respondents. In Estonia, existing school and healthcare facilities and capacities are adequate, although study says more can be done to make them accessible to the disabled people Education is compulsory and made available for all children and the displaced people's children have the same right and access to education as the children of their host countries. However, displaced communities need improved support to access healthcare, school, social care, language tuition, education funding (grants or loans), and childcare for women with children.

In the case of Sweden, it was found out that many refugees do not get to meet Swedes and practice talking Swedish in school, as there are no native Swedish speaking children in the schools that they attend. To have a segregated education system where newly arrived are placed in separate classes is a major barrier for social integration. In order to achieve mutual understanding, it is important to break the segregation. But if the segregation starts from the education system, it is impossible to make the social integration between displaced and host. Therefore, adequate and equal access to education for displaced same as the host can be identified as a foremost need contributing to human capital and social cohesion.

Adequate provisions and support to gain and match the employability skills and professional qualifications of the displaced to the new context. In most cases, the majority of them who had good jobs back home would not be able to work in their professional fields if their qualifications are not recognized. As an example, in the UK, some respondents gave reason for not gaining employment as their experience not relevant to the UK, which makes professionals end up with manual jobs like care-work, security work, receptionist works, and the likes. Some of the refugees already had qualifications and had been employed or self-employed before coming. This previous experience might make it less challenging to gain employment that is suited for their level of qualification. In such instances, provisions and support to gain and match the employability skills and professional qualifications of the displaced to the new context are important in rebuilding communities and enhancing social cohesion.

UNHCR report from 2013 points this out stating that there are some structural barriers common for all refugees influencing integration, but states that the solution rather lies in a more individual approach with adjusting of resources and activities rather than general changes (UNHCR, 2013 cited in Wahlström & Ivarsson, 2015, p. 7). In the Sweden context, few points were made by municipality representatives as to what measures have helped overcome the barriers mentioned above. Among these where measures seeking to ensure that refugees get a first work experience, which was ensured by municipalities hiring refugees in their operations in projects giving opportunities to proper work for a decent salary; and municipalities cooperating with trade and industry as well as voluntary and other organizations to provide internships. Swedish municipalities try to help with identifying the competencies of refugees and provide proper documentation, as to facilitate employment; and actively investing in individuals born abroad and in supporting them in the process of starting one's own company.

Considering the above facts, the following factors can be considered as important interventions in gaining and matching the employability skills and professional qualifications of the displaced to the new context.

- Initiatives to provide one-to-one support to gain employability skills and professional qualification
- Single authorised body/institution for the recognition and comparison of international qualifications and skills
- Direct displaced to this institution at the initial integration stage
- Provisions on improved and easy access to vocational training centres in different skills.

In terms of developing human capital, it was found that provide orientation related to local integration has a significant effect on the smooth integration of displaced to the new environment. Here the orientation should include orientation to climate, financial support and management, housing, rights and responsibilities, employment, culture, and politics, available services and facilities of the receiving country or region. It was found that most asylum seekers/ refugees are not aware of welfare benefits/ financial support before arriving in the receiving country. This makes most of those displaced communities live in poverty which culminates in poor health, hunger, homeless, and destitute. Lack of cultural awareness and understanding of employment opportunities of the receiving country/region, result in displaced communities take a long time to settle in the new environment.

However, when providing the orientation, it was also found that the orientation given them prior to their arrival created some misconceptions and unreasonably high expectations about aspects of the new life (Especially in the context of Europe/UK). Therefore, resettlement programs should orient the displaced to both challenges and potentials of the new environment by showing the practical/real-world situation of the receiving country/ region. Further, if every displaced community can go through this type of orientation program, the resettlement process will be smooth and firm.

Another aspect related to human capital is the need of providing awareness of cultural differences to the professionals/officials who work in the resettlement process. For instance, it was found that health and wellbeing in some cultures are believed to be deeply rooted in religion, which is considered to play an important role within the community life. Professionals who are dealing with cultural communities should be aware of those. Lack of cultural awareness and understanding of refugee concerns by the support professionals and the limited provision of culturally appropriate facilities and services for the refugees and asylum seekers. Currently, in countries such as the UK for health professions alike, there are race, equality, and diversity of cultural competency training which can be adapted to the professionals/ officials who work in the resettlement process. Likewise, creating real-world/practical based awareness/training programs for professionals/ officials who work in the resettlement process and making basic equality and diversity of cultural competency training as an essential part or requirement of the professional competency ladder are identified as an effective strategy to provide awareness on cultural differences to the professional and officials in resettlement planning.

4.6 Protect: Natural Assets

In the context of displacement and resettlement planning, the built environment plays a significant role to protect and promote natural assets. The first most important is to avoid resettling environmentally sensitive and hazard-prone areas and minimize the emergence of new risk. In that case, there is a need of identifying the hazard-prone areas and demarcate them before displaced resettle in those areas.

Secondly, the way the built environment is arranged can maximize the displaced communities' access to natural resources and the environment. Displaced communities need access to natural resources but in a sustainable matter. Especially for some communities the access to natural resources is important as it linked with their way

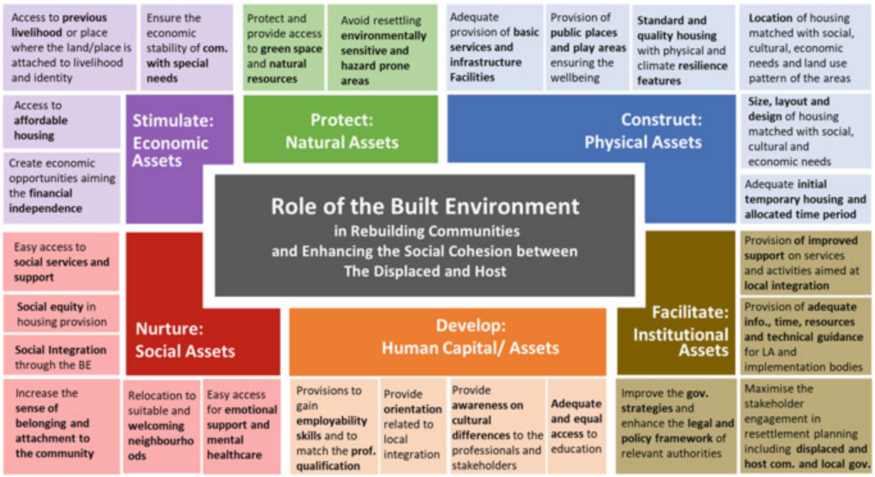

Fig. 2 Role of the built environment in rebuilding communities

of living as an example firewood for cooking or sometimes access is important for agricultural purposes.

Apart from that, access to natural and green environments is important to the phycological wellbeing of people. Sometimes the displaced people are already battling depression and stress, the inability to access the natural environment could also increase their stress, and wellbeing consequently. Adding to this, Burton (2014) and Cooper (2014) both submit that an improved built environment assists mental health and wellbeing. Previous studies have demonstrated that access to adequate daylighting, natural views positively influence the physiological wellbeing of people (Janayi et al., 2018). Therefore, visual and physical access to green space and natural resources can be identified as an important intervention in relocation and resettlement planning.

In summary, all the above-discussed interventions across the six perspectives; construct physical assets, stimulate economic assets, facilitate institutional assets, develop human capital assets, nurture social assets, and protect natural assets can be illustrated as follows (Fig. 2).

5 Conclusions

Research findings propose that the built environment has an imperative role to play in rebuilding displaced and host communities and enhancing the social cohesion by acting across six perspectives; constructing physical assets, stimulating economic assets, facilitating institutional assets, nurturing social assets, developing human capital assets, and protecting natural assets.

In constructing the physical assets, six interventions have been identified related to the built environment. Firstly, adequate provision of standard and quality Housing for all the types of displaced. Secondly, adequate initial temporary housing and allocated period. Thirdly, match the location of resettlement housing with social, cultural, and economic needs of displaced communities. Fourthly, match the size, layout, and design of resettlement housing with the social, cultural, and economic needs of displaced communities. Fifthly, adequate provision of basic services and infrastructure facilities without limiting the capacity of the host. Sixth intervention is the provision of public places and play areas Ensuring the wellbeing of both adults and children.

In order to stimulate the economic assets, the built environment can play a major role across four interventions; ensure the access to affordable housing, Access to previous livelihood, create economic and employment opportunities aiming the financial independence of displaced communities, and ensure the economic stability of communities with special needs.

Facilitating institutional assets is another role of the built environment which needs to be operated in four main areas in the context of displacement. Firstly, in the provision of improved support on services, advice, and activities aimed at local integration and assistance. Secondly, in the provision of adequate information, time, and resources for local councils/municipalities to prepare the reception of refugees. Thirdly, to maximize the stakeholder engagement including displaced and host community's engagement and the host local council/ municipalities' engagement when preparing resettlement plans. Fourthly, to improve the government strategies and structure the investment for creating and building inclusive societies for displaced.

The built environment can nurture the social assets in the context of resettlement planning by providing easy access to social services and support, social equity in services and housing provision, easy access for emotional support and mental healthcare, relocating displaced to suitable and welcoming neighborhoods, promoting social integration through the built environment and finally, by increasing the sense of belonging and attachment to the community through the built environment designs and interventions.

In developing human capital assets, provisions to gain and match employability skills and professional qualification matching to the new context, adequate and equal access to education, provide orientation related to local integration and provide awareness on cultural differences to the professionals and stakeholders are found to be an important intervention. The sixth perspective of the built environment is the ability to protect and promote the natural environment which can be achieved through avoidance of resettling environmentally sensitive and hazard-prone areas and protect and provide access to green space and natural resources.

In conclusion, this chapter introduces a comprehensive framework (Fig. 2) to understand the multifaced role of the built environment in rebuilding communities and enhancing social cohesion. Further, vigilant consideration of these six perspectives of the built environment benefits the professionals who work in resettlement planning to plan, design, and construct the built environment in rebuilding communities and enhancing social cohesion between displaced and host communities.

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Strategy for the Establishment of Local Disaster Risk Reduction (DRR) Plans in Sri Lanka: A Study on Its Effectiveness and Challenges Through a Pilot Programme

Takayuki Nagai and R. Priyantha Samarakkody

Abstract To formulate Local DRR plans, compliance with laws and policies at all levels, as identified under the SFDRR, is essential. The JICA supported the initiatives of Disaster Management Division and DMC of Defense Ministry, Sri Lanka to form the National Strategy to establish Local DRR Plans, through a pilot programme to study the practical usefulness of JICA-compiled "8 Steps Guide" to facilitate the compliance to the SFDRR. The Kalu River basin was identified as a target basin with four pilot areas. Rain-induced disasters were selected as target disasters, with a view to establishing a methodology for local DRR planning which is extensible to other geographical areas and disasters. A series of workshops with National, Sub-National and Local level stakeholders were conducted, where the essential elements of Local DRR plan based on the 8 Steps Guide were discussed, such as "Identifying risks and residual risks", "proposed countermeasures", "budget allocations" and "structures for the implementation and periodical review". While the practical usefulness of 8 Steps Guide with participatory approach was generally verified in positive, issues requiring an elaborated planning methodology and strategy were also identified, such as "to clarify the roles of local organizations in DRR with institutional set-ups, thereby securing the accountability and funding for the execution of countermeasures".

1 Introduction

In recent years, natural and man-made disasters seem to become larger in scale and more frequent (e.g. Japan Meteorological Agency, 2019). Disaster-prone areas are also expanding and changing constantly in geographical as well as in socio-economic terms. Climate change could also aggravate this situation (e.g. Ministry of Land, Infrastructure, Transport and Tourism, Japan, 2018). In addition, rapid increase in

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development activities without proper attention to disaster risks is considered to be an aggravating factor to increase new disaster risks.

Against the above background, the concept of disaster risk reduction (hereinafter referred to as DRR), which calls for investment in the prevention or mitigation of disasters rather than the response to them, has been highlighted in recent years. While the DRR has become the mainstream concept in disaster management sector internationally, the application of DRR in each country, particularly at local level compared with national level, has been facing various challenges.

The purpose of this paper is to introduce the strategy adopted in Sri Lanka for the establishment of Local DRR Plans, with the focus on the "8 Steps Guide" compiled by the Japan International Cooperation Agency (hereinafter referred to as JICA), as a key guiding instrument. The outline of Pilot Programme conducted to study the practical usefulness of 8 Steps Guide, the outcomes and the findings of the Pilot Programme as well as their implications on the overall strategy will be discussed, followed by the concluding observations on the directions to be followed in future.

1.1 Sendai Framework for Disaster Risk Reduction (SFDRR)

In 2015, the "UN World Conference on Disaster Risk Reduction" was held in Sendai, Japan, with the participation of about 180 countries including Sri Lanka. The Sendai Framework for Disaster Risk Reduction (hereinafter referred to as SFDRR) was adopted as one of the outcome documents of this conference.

Among the seven Global Targets stated in the SFDRR, only the Target (e) which is to "substantially increase the number of countries with national and local disaster risk reduction strategies" has the year 2020 as the target year, while the other six targets have a common target year of 2030. The underlying concept is to enhance the efforts for the other six targets by fulfilling the Target (e) first, since the national and local strategies provide the bases for all the other activities to address Disaster Risk Reduction.

Based on this Target (e), each country is thus mandated to formulate its national and local DRR Plans (UNDRR, 2015: 18. et al.).

1.2 Situation of Sri Lanka

In Sri Lanka, the 5-year National Disaster Management Plan was established in 2013. Accordingly, the Local Disaster Management Plans were formulated in all the 25 Districts and the majority of Divisional Secretary Divisions. However, those plans are focusing on emergency responses at the times of disaster, without addressing the preventive aspects including the needs for countermeasures to reduce disaster risks.

Also, the existing plans basically consider disaster management as a responsibility of the Central Government (e.g., District Secretariat Batticaloa, 2012). As a consequence, the engagement of "Local Government and all the society", as intended by SFDRR, have not been incorporated in those plans yet.

Therefore, it is an urgent task for Sri Lanka to formulate Local Disaster Risk Reduction Plans (hereinafter referred to as Local DRR Plan) in line with national policies and regulations to fulfil its commitment to the SFDRR, focusing on the element of 'Disaster Risk Reduction' and preventive measures, with the active involvement of local authorities and other local organizations.

1.3 Strategy for the Establishment of Local DRR Plans in Sri Lanka

In the SFDRR, the basic concept of DRR is explained in the 13 Guiding Principles. It states that the state should be responsible for disaster risk reduction (UNDRR, 2015: 19. (a)), that all levels of stakeholders and related organizations should participate (UNDRR, 2015: 19. (e)), and that it is necessary to empower local authorities and local communities to reduce disaster risk as appropriate (UNDRR, 2015: 19. (f)). Based on this idea, the Disaster Management Centre (hereinafter referred to as DMC) with JICA intended to support the formulation of Local DRR Plans in Sri Lanka by widely calling for the participation of relevant organizations in the local administrative system, to discuss the importance, positioning and necessary contents of Local DRR Plans.

In order to establish Local DRR Plans in numerous local administrative areas in Sri Lanka within a limited time frame, DMC is in the process of drafting the National Strategy to establish Local DRR Plans (hereinafter referred to as "the Strategy"), a broad and innovative strategy to enable the formulation of Local DRR Plans in a systematic and efficient manner, while incorporating all the required elements as per the SFDRR. One of the key components of the Strategy is to produce guiding materials containing a practical and detail methodology to formulate Local DRR Plans, and to disseminate them to all the local areas in the country.

In this regard, the JICA supported the DMC's initiative by introducing the "8 Steps Guide" as one of the key guiding materials. It also supported a pilot programme during 2019–20, to study the practical usefulness of 8 Steps Guide through its trial application to the pilot areas, as described down below (Sect. 2).

1.4 JICA's "8 Steps Guide"

1.4.1 Outline of the "8 Steps Guide"

"8 Steps, Practical Method for Developing Local DRR Strategies/ Plans" (hereinafter referred to as the "8 Steps Guide") which was compiled by JICA, contains the practical and feasible method to develop a local disaster risk reduction strategy/plan with concrete measures for investment (Fig. 1).

The 8 Steps Guide is based on the idea of the SFDRR. The local governments and stakeholders will conduct risk assessments by themselves (UNDRR, 2015: 19. (f)), and consider disaster prevention measures for those risks. The main theme of Local DRR Plans is to consider concrete measures that are specially designed for disaster prevention (UNDRR, 2015: 7.).

Only few developing countries have already implemented Local DRR Plans (UNDRR, 2020), and even though they did, most of the plans only contained actions

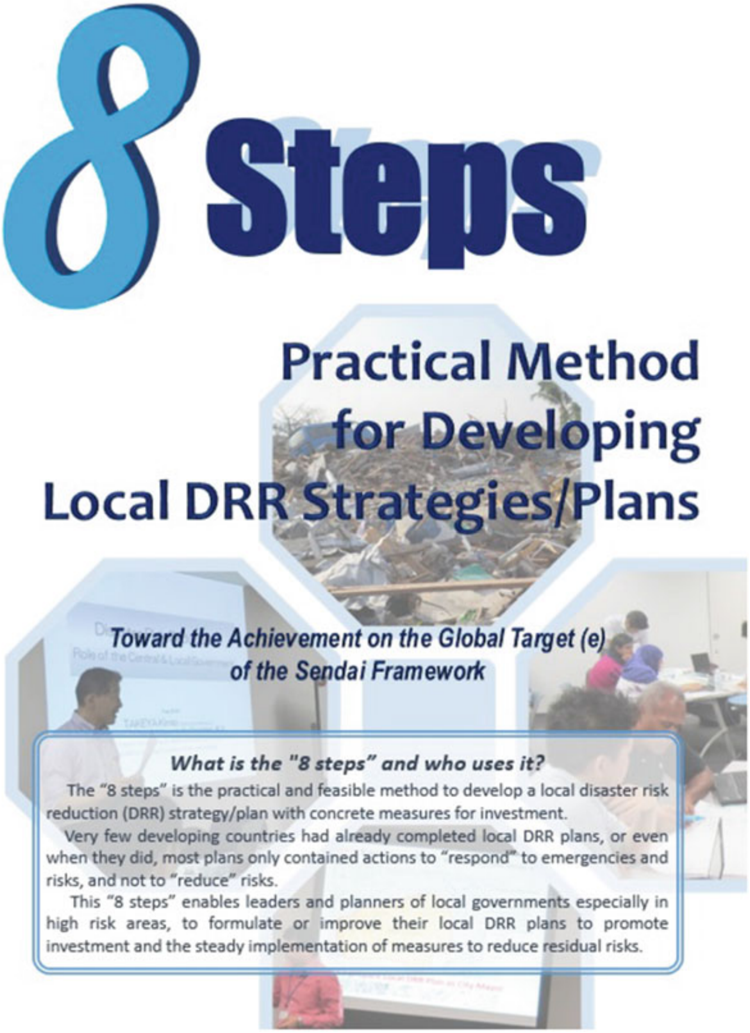

Fig. 1 Image of 8 steps guide

to "respond" to the emergencies and risks, not to "reduce" risks. This "8 Steps Guide" enables leaders and planners of local governments especially in high risk areas, to formulate or improve their Local DRR Plans with arrangements to promote investment and to ensure the steady implementation of countermeasures to reduce residual risks.

1.4.2 Contents of the "8 Steps Guide"

The Step to formulate Local DRR Plans according to the "8 Steps Guide" are described down below. The general procedure is: "Selection of target hazards and target areas (Step 1)", "Risk evaluation (Step 2–4)", "Selection of priority measures (Step 5–6)", and "institutional arrangements for the execution of, securing budget for, and the periodical review of the DRR measures (Step 7–8)". With its simple description and practical work flow, the 8 Steps Guide is designed to be a suitable guide for relevant officers at local level to formulate a Local DRR Plan by themselves.

Moreover, these steps are in line with the priority actions in the SFDRR, in particular the priority action 1 "Understanding disaster risk" (UNDRR, 2015: 23.), and the priority action 3 "Investment in disaster prevention for resilience" (UNDRR, 2015: 29.). Therefore, by following these steps and implementing the plan, "preventing new risks and reducing existing risks", which is one of the important goals of the SFDRR (UNDRR, 2015: 6.), can be achieved.

Step 1: Collecting local hazard information.
Step 2: Understanding local disaster risks.
Step 3: Understanding DRR plans by national and other higher authorities.
Step 4: Identifying residual risks considering time-series.
Step 5: Listing all the DRR measures required by local governments.
Step 6: Prioritizing DRR measures.
Step 7: Arranging budget allocation at necessary levels.
Step 8: Implementing DRR measures and reviewing periodically.

2 Pilot Programme for Drafting Local DRR Plans

2.1 Purpose of the Pilot Programme

Based on the situation described above, the DMC with the support of JICA implemented a pilot programme utilizing the "8 Steps Guide", from July 2019 to June 2020. The main purposes of Pilot Programme were as follows.

- To study the practical usefulness of the 8-Step Guide in Sri Lankan context through its test application at a series of workshops to formulate Local DRR Plans, in particular:

  - whether it facilitates the discussion in line with SFDRR, and
  - whether Local DRR Plans are formulated in systematic and efficient manner with all the elements of SFDRR incorporated in it;

- To verify the methodology to organize and conduct Workshops including the participatory approach, and obtain feedbacks from participants; to identify any issues in the contents or methodology, to identify any other bottlenecks for the formulation of Local DRR Plans;
- To obtain inputs from the participants to the draft of Guideline with template which is to be finalized and utilized for dissemination activities in future;
- To transfer the knowhow of managing workshop and drafting process on Local DRR Plans to the participants and DMC officers.

The overall goal of the Pilot Project was to obtain insights on the methodologies to formulate Local DRR Plans, and to reflect them to the national strategy. Although the Pilot Programme was conducted in specific areas and for specific hazards, once the Strategy and methodology are finalized for such hazards and areas, the same mechanism can be extended to incorporate other hazards and areas with adding other stakeholders involved.

2.2 Methodology of the Pilot Programme

2.2.1 Target Area

Local DRR Plans should be formulated at each level of local administration, so that local organizations at each level can manage disaster risks by themselves. In Sri Lanka, (i) Local Authority (hereinafter referred to as LA) and Divisional Secretariat (hereinafter referred to as Div.Sec.), (ii) District, and (iii) Province are the levels at which Local DRR Plans need to be formed. Grama Niladhari (hereinafter referred to as GN) level plans (or guideline) may also be needed to reinforce LA / Div.Sec. level plans (Fig. 2).

However, the most basic unit of local administration is LA. This is because LAs have their own development plans approved by elected councils, which can play a significant role in securing a budget essential for DRR activities, by receiving investments in their development plans. Therefore, LA and other local organizations ideally should play a major role for disaster prevention in the area, and especially LA should be considered as the basis when clarifying the role of local area in disaster risk reduction.

However, in actual practice, LA and Div.Sec. are functioning complementarily in providing various services to the people in the area, though the latter belongs to national administrative line. Hence, from a practical and realistic point of view, it was decided to formulate a joint Local DRR Plan for LA and Div.Sec., which share almost the same geographical area, during the Pilot Program.

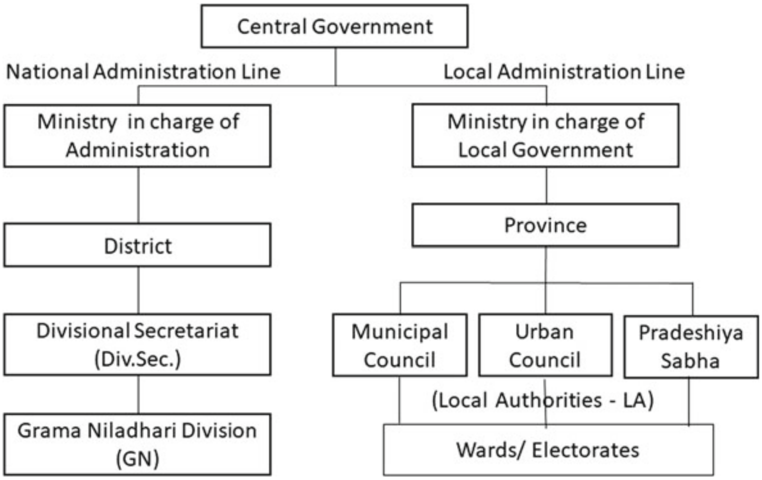

Fig. 2 Composition of national and local administrative lines

As a result of discussion with executives of the Disaster Management Ministry, the Kalu River basin was selected as a pilot basin in consideration of past disaster status and frequency. The Kalu River is a river with a basin area of approx. 2700 km^2, the second largest in Sri Lanka, that flows through the Southwestern part of the country from Ratnapura District to Kalutara District (Fig. 3). After discussions with relevant Provincial Councils, Districts, Div.Sec., etc., the following four pilot LA/Div.Sec. areas were selected: “Bulathsinhala LA/Div.Sec”. and “Kalutara LAs/Div.Sec”. from Kalutara District, and “Ayagama LA/Div.Sec”. and “Nivithigala LA/Div.Secs”. from Ratnapura District. However, the workshops were actually held only in the two areas of Bulathsinhala and Ayagama during the program period due to time constraints.

2.2.2 Target Hazard

According to SFDRR, all kind of disasters should be considered in formulating DRR plans. However, each drafting process can take up only one disaster at a time. Considering the limited time frame of the Pilot Programme, it was decided to focus on “rain-induced disasters” which have higher priority in the pilot areas than the other disasters.

The initial identification of hazards may include riverine flood, flash flood, landslide, cutting failure, rockfall, soil erosions etc. as rain induced disasters, as well as other disasters accompanying rain such as lightning, strong wind, epidemics, traffic accidents, sedimentation, contamination, etc., which were actually raised during the workshops.

Thereafter the participants of the Pilot Programme must prioritize the disasters and select two hazards which have the most significant risk in their respective areas.

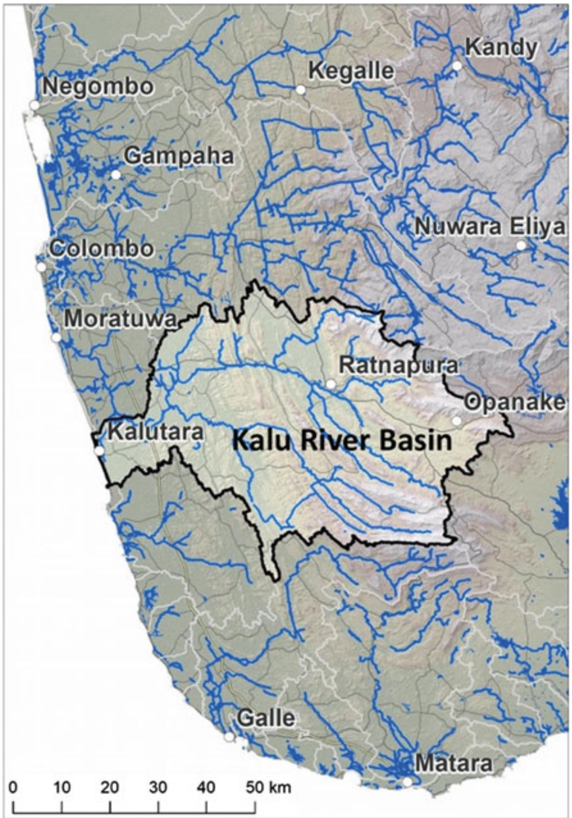

Fig. 3 Kalu river basin

Specific hazards were discussed at the workshops, resulting in "flood" and "landslide" selected in both pilot areas, as mentioned down below (Sect. 2.4).

2.2.3 Organizational Setup (1): Committees and Working Groups at Each Local Level

Local DRR Plans should be formulated by local organizations, because the local organizations have best knowledge of local problems, and therefore they are the most suitable organizations to manage local disaster risks. However, the formulation process and the results of discussion need to be authorized at each level such as LA/Div.Sec., District and Province, in order to ensure coordinated efforts for Local DRR activities.

Therefore, the Pilot Programme proposed the organizational set up shown in Fig. 4. LA and Sub-national organizations such as Div.Sec., which covers an identical area with LA, are to form Working Groups and upper authorities such as Provinces and Districts are to perform coordinating function. Then, at the Central Government level,

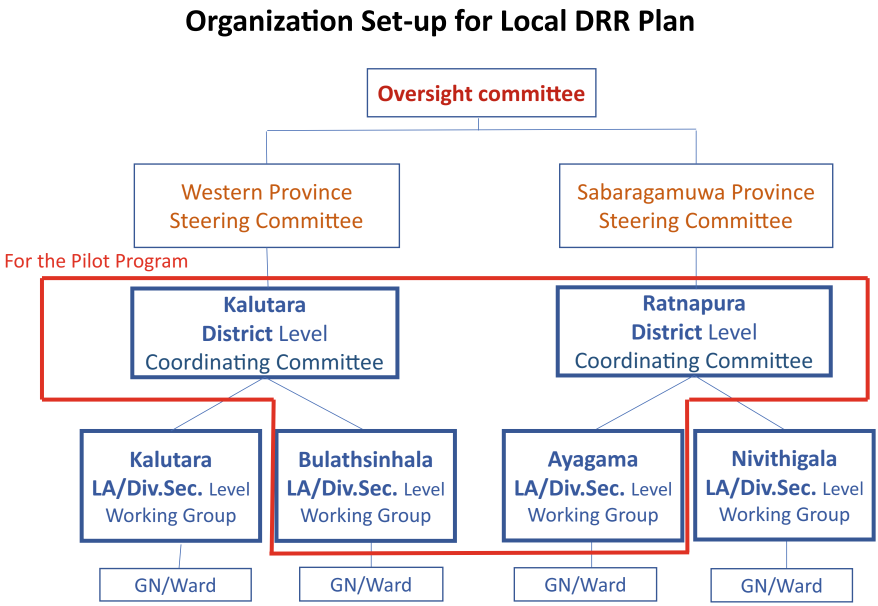

Fig. 4 Organizational Setup for Local DRR Plan

Oversight Committee is to be set up as a decision-making forum at national level. Considering the limited time frame of the Pilot Programme, an initial goal was set to operate Working Groups at the LA/Div.Sec. level and Coordinating Committees at District level, while only the Working Groups were actually established due to time constraints.

2.2.4 Organizational Setup (2): Proposed Members for Committees and Working Groups

As the result of discussions held at the relevant Provinces, Districts, Ministry in charge of disaster management and DMC, members of LA/Div.Sec. level Working Group and District level Coordinating Committee members were proposed as shown in the Tables 1 and 2. A wide range of relevant institutions were extensively listed as proposed members, in accordance with the Guiding Principles of SFDRR as described in the Sects. 1.3 and 2.2.

In particular, executives of LAs, Div.Secs. and other institutions as well as political leadership at LA level are considered as the essential members of the Working Groups, because various important discussions and decisions on DRR will be made at Working Groups.

Table 1 Proposed members for Workshop (LA/Div.Sec. level Working Group)

Organization	Proposed Officer
Divisional Secretariat	Secretary (Chair), Divisional Officer of National Disaster Relief Service Centre, and Other relevant officers
Local Authority	Chairman (Co-Chair), Secretary of LA and Other relevant officers
Grama Niladahri Division	Gramaniladari (GN)
District Officers	DMC(facilitator), National Building Research Organization, Irrigation Department, Met Department, Road Development Authority, Urban Development Authority, Ceylon Electricity Board, Sri Lanka Telecom, Water Board, etc.
Provincial District Officers	Assistant Commissioner Local Government and other related officials
Other Officers	Police, Military, Education, Health, etc.

Maximum 35 members

Table 2 Proposed members for District level Coordinating Committee

Organization	Proposed Officer
District Secretariat	Secretary (Chair), DMC Officer, Officer of National Disaster Relief Service Centre, Other Officers
Provincial Council	Commissioner Local Government (Co-Chair) and other Provincial Officials responsible for District activities
Local Authority	Chairmen of target LAs, Other officers
District Officers	National Building Research Organization, Irrigation Department, Met. Department, Road Development Authority, Urban Development Authority, Central Environment Authority, Ceylon Electricity Board, Sri Lanka Telecom, Water Board, etc.
Other Officers	Police, Military, Legal, Health, Education, etc.

Approx. 20 members

2.3 Implementation of a Series of Workshops

The LA / Div.Sec. level workshops were initially scheduled for three times in each pilot area, with the expected agenda as follows;

1st Workshop: To share the background information including SFDRR and the necessity to formulate Local DRR Plans; and to implement Step 1 to Step 5 of the 8 Steps Guide.
2nd Workshop: To implement from Step 6 to Step 8 of the 8 Steps Guide, and decide on the sharing of the drafting work among relevant organizations.
3rd Workshop: To review the all results of 8 Steps and finalize the draft of Local DRR Plan prepared by the drafting members.

However, the actual progress was made only up to the 2nd Workshop in each pilot area, due to various factors including Covid-19 issues.

2.4 Result of Discussions at the Workshops

The following discussions were held at the and prior meetings, with the participation of executives of LAs and local organizations such as Divisional Secretaries. The DMC officers performed a role of facilitator of the workshops and preparatory meetings (Figs. 5 and 6).

2.4.1 Discussion Based on the 8 Steps Guide

Floods and landslides were selected as priority hazards in both of the pilot areas. It was pointed out that careless activities of people often become the causes of disasters, such as the obstruction of drainage due to urban development, road development without considering disaster risks, discharge of dams without taking into account the water levels of the river, and illegal house construction. It was also pointed out that flooding of the main river caused floods in the tributaries (Backwater phenomenon). Not only physical or structural matters, but also systematic or non-structural issues were pointed out, such as the lack of disaster consciousness of local people. Also, it was pointed out that LA officers did not consider the disaster management to be their duty (Steps 1–4).

Fig. 5 Workshop in Ayagama

Fig. 6 Workshop in Bulathsinhala

As measures to resolve them, several structural measures were proposed such as constructing bunds or retention ponds, felling of old trees etc. Also, non-structural measures such as “the mainstreaming of disaster risk reduction in local area”, “improvement of recognition of LAs for disaster risk reduction work as their own obligations”, and “allocation of budget for disaster risk reduction to LAs and local level organizations” were recommended by the participants (Steps 5–8).

2.4.2 Assignment of Drafting Work

After proceeding to Step 8 in the second workshop, the division of roles in drafting a Local DRR Plan was discussed. Depending on the content and characteristics of each chapter, an organization in charge of drafting the chapter was appointed among relevant organizations including Div.Sec., LA, the local office of the Central Government, etc.

3 Results of the Pilot Programme

3.1 Progress of the Programme

Due to the influence of the Covid-19, the progress of Pilot Programme was unfortunately delayed. The results of Pilot Programme so far are described as follows.

- The workshops were initially planned to be held three times in each pilot area. However, only two workshops have been held in each of the two pilot areas at the moment.
- Since the pilot areas are frequently hit by disasters, LA / Div.Sec. officers were highly interested in disaster risk reduction, and there was active participation and discussion among participants.
- Discussion on all the steps from Step 1 to Step 8 was completed. For the next stage of drafting the Local DRR Plan by the local officials, drafting task has been assigned to relevant officers in charge of each chapter.
- However, the submission of draft is still pending due to the influence of the Covid-19 as of September 2020. In order to facilitate the drafting process, the DMC has compiled the sample drafts of Local DRR Plans based on the discussion and written submissions made at the Workshops. The sample drafts is expected to be presented to local officials to demonstrate drafting methods as examples.

3.2 Findings of the Pilot Programme

Various discussions were held during the workshops and prior meetings with local executives. Following items were found as the results of discussions. (Picked up from the minutes of discussions: c.f., Sect. 2.4 Result of Discussions).

- There are some specific causes of disasters due to human activities such as illegal construction of houses.
- Developments ignoring disaster risks may cause disasters.
- There is no specific plan for preventive measures in local areas under the current national or local programme.
- No responsibility for disaster prevention has been granted to local areas under the present administrative system, with the central administrative line basically holding the responsibilities related to disaster management.
- No specific budget or fundraising mechanism to address prevention of disasters in local areas.

3.3 Output of the Pilot Programme: The Guideline with Template

Based on the findings from discussions in the workshops and the prior meetings, the Guiding Principles of SFDRR, and the experience of one of the authors in formulating disaster risk reduction plans in Japan, "The Guidelines for Drafting Local DRR Plans" were formulated as one of the main output of the Pilot Programme.

3.3.1 Template to Facilitate Drafting Work

The feature of this guideline is the template for Local DRR Plans. Considering the difficulty for the local officers who do not have experiences in formulating Local DRR Plans, particularly the difficulty they will face in risk assessment and proposing countermeasures, the initial version of template was created in advance and utilized in the series of workshops. The drafters can make a draft of Local DRR Plans with the template instantly, and after the initial formulation of the plan, they can gradually make further improvements later with their own input, so that it will become a plan with originality.

3.3.2 Comprehensive Guideline with Informative Resources

After utilizing the Guideline on a trial basis at the workshops, improvements were made to the Guideline to reflect the comments from participants which were obtained through the workshops. By adding background information such as explanations of the reasons for necessity to formulate Local DRR Plans, the outline of SFDRR, and the points to be noted at each Step, the Guideline was finalized as a comprehensive guiding material. It is one of the main outcomes of the Pilot Programme.

3.3.3 Contents of the Guideline with Template

Contents of the Guideline are as follows;

- Purpose and Scope of the Guideline
- JICA 8 Steps Guide and its background
- JICA 8 Steps Guide
- SFDRR
- Global Targets
- Target (e)
- Disaster Management Cycle
- What is Local DRR Plan?
- The Pilot Programme
- Outline and Scope

- Target Disasters
- Organization Setup
- Proposed members for committees and working groups
- Methodology and Preparation
- Drafting Guide with Template.

4 Observations on the Results of Pilot Programme

In light of the purposes of Pilot Programme as described in Sect. 2.1, the following observations are made on the results of Pilot Programme.

- Practical usefulness of the 8 Steps Guide: The 8 Steps Guide is evaluated to be a useful tool to guide and facilitate the discussion at the workshops. By following the 8 Steps, all the essential elements of Local DRR Plans were covered, providing necessary information and concepts for the drafting work.
- Participatory approach was found to be an effective method to extract local knowledge and to reflect such knowledge to the Local DRR Plan. Though the details need to be elaborated further, it is highly recommended that the approach will be maintained in future exercises as well.
- Guideline with Template as an output of the Pilot Programme: The Guideline finalized with the feedback from the participants of workshops contains the basic concept of DRR, the methodology, concrete procedures and templates to formulate Local DRR Plan based on the 8-Step Guide. Due to its convenience to the users, it is expected that Guideline will be utilized in Sri Lanka as needed for the promotion of Local DRR Plans.
- Issues identified in Sri Lankan context: Since there is no specific budget for disaster risk reduction, and the role of the LA and other local organizations has also not clearly defined under the current administrative system, opportunities of local organizations to tackle disaster risk reduction are less. This needs to be addressed by the national level strategy in order to promote Local DRR Plans further.
- Participants' awareness on DRR: Although the Local Development Committees have discussed 'disaster management', the main focus of participants was often on the response and relief at the time of disaster. In order to ensure the discussion on preventive measures, continuous efforts to raise awareness of participants on DRR will be necessary.
- Organizational setup: The necessity to establish a permanent organizational structure by both the Central Government and Local Authorities with the main task of disaster risk reduction, such as the one proposed in this Plot Programme. LAs should discuss what is to be done for disaster risk reduction in that framework, and the Central Government should provide necessary support to them.
- Capacity building of the participants: Though the Templates are provided to the drafters to make the drafting process easy and quick, the process of thinking and planning by the local officials in the area is very important in itself.

- Maps and data management: For the group works of the workshops, printed maps of the target area were used. However, due to the small scale of the maps, the information available on the maps was limited. Also, for the risk assessment, participants required the lager maps to share their geographical knowledge. Ideally, a map based on satellite images would be helpful for the participants to identify the exact location of facilities and infrastructures. By displaying the maps on a PC for each group and allowing to input their knowledge and related information directly into the GIS database during their discussion, the efficiency of discussion and drafting work will improve drastically. This point also needs to be addressed by the national level strategy.

5 Conclusions

As described above, various meetings, discussions, and the series of workshops were held during the Pilot Programme. The basic concept and methodology for the formulation of Local DRR Plan were summarized in the previous sections. The discussions on the ideal means of disaster risk reduction in local areas and the efforts to nurture a common understanding and concrete vision on the required Local DRR Plan need to be continued and deepened in future.

While the practical usefulness of 8 Steps Guide for the formulation of Local DRR Plan was generally verified in positive through the pilot study programme, the findings of this study also identified several issues which need to be addressed by elaborating the planning methodology, as well as by enhancing the overall Strategy. Examples of such issues include the "necessity to clarify the roles of local organizations in DRR, and to establish inter and intra organizational set-ups accordingly, in order to secure the accountability and fund allocations for the execution of proposed countermeasures".

While the position and roles of local organizations in disaster risk reduction is not clearly defined under the current administrative system in Sri Lanka, it is of great significance for local organizations to engage in discussion on the issues to seek the solution and to provide suggestions for such solution.

In addition, the finalized Guideline with templates are expected to contribute to the formulation of local DRR Plans in various local areas in Sri Lanka, through their effective utilization in future. Sharing the Sri Lanka's experience will potentially contribute to the local DRR activities in other countries as well.

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Disasters, Climate Change and Development Nexus: Food Security Sector in Asia

S. J. K. Madurapperuma, Dilanthi Amaratunga, and Richard Haigh

Abstract Climate change is one of the leading development challenges faced by humankind in the twenty-first century. One end, it has resulted from the aggressive development drivers and rapid economic growth. On the other end, climate change, extreme events, and associated hydrometeorological disasters, directly and indirectly, setback the development gains. Climate change mitigation can be accelerated through sound development policies, strategies, and programs. Climate change adaptation, coupled with upscaled disaster risk management, contributes to reducing the negative impacts of extreme events and other socio-economic shocks. Climate change, weather extremes, and disasters adversely impact food production and productivity in developing countries. Food security and access to food are considered fundamental human rights. The Sustainable Development Goals (SDGs), goal number two, "Zero Hunger" to be achieved by the year 2030, highlights the importance of food security across the countries. However, achieving the 'Zero Hunger' milestone has been challenged due to climate change, extreme events, and disasters. Although there is a general consensus about the linkages between climate change and food security, the nexus between disasters, climate change, and sustainable development and their interconnections with food security have not been fully explored or well understood. Asia region, which homes to two-third of the world population and the highest number of reported annual disaster events, face unprecedented challenges in meeting food security and access to foods in the coming decade. Within this context, this chapter explores the complex inter-connectedness of disasters, climate change, and development in the food security sector in Asia.

Keywords Disasters · Climate change · Climate change adaptation · Food security · Risk reduction · Sustainable development

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1 Introduction

Disasters account for unprecedented impacts globally, regionally, and locally. Climate change is further amplifying the effects across vulnerable countries in the region. Frequency, seasonality, and intensity of climate-induced hazards have shown significant differences across the region, having adverse impacts on fragile sectors such as Agriculture, Water Resources, Health, among others (WMO, 2018). Food security, which determines the physical, social, and economic access to sufficient, safe, and nutritious food that meets their dietary needs and food preferences for an active and healthy life, has been compromised in many parts of the world due to the impacts of disasters and climate change (FAO, 2013). Chronic impacts of climate change, such as the sea-level rise and temperature changes, have impacted the production and productivity of the Agriculture sector. Furthermore, climate-induced hazards have direct impacts on the performance of food security in developing nations as their consumption heavily dependent on local production, productivity, and other economic factors. Sustainable Development Goal (SDGs) Two; 'Zero Hunger' aims to end hunger, achieve food security, and improved nutrition, and promote sustainable agriculture (UNDESA, 2020). However, the progress and process have been challenged by climate change, disaster impacts, and their nexus with development pathways. Climate change and disasters will not only impact SDG two but also other goals such as Goal 1 (No Poverty), Goal 3 (Good Health and Well-being), Goal 4 (Quality Education), Goal 6 (Clean Water and Sanitation), Goal 11 (Sustainable Cities and Communities), among others. Therefore, this chapter discusses the nexus between disasters and climate change and their cumulative impacts on the food security sector within the overall framework of Sustainable Development Goals. The chapter synthesizes several studies and literature on the nexus between climate change, disasters, and their interconnectedness with food security and development paradigms in Asia. The chapter also discusses about major global frameworks for development (SDGs), Sendai Framework for Disaster Risk Reduction, and the Paris Agreement on Climate Change and the need for having an integrated approach in resilience at country and local levels within the overall framework of Sustainable Development.

Asia is home to two-thirds of the world population. On the other hand, it substantially contributes to global, regional, and national food security and an integral part of the global food supply chain. The region is also highly vulnerable and considered a hotspot for disasters. Therefore, the next section of the chapter will discuss disaster impacts in Asia.

2 Disaster Impacts in Asia

Disasters occur as a result of complex interactions between hazards, elements at risk, and their consequences that go beyond the capacity and resources of the communities in a given context. Disaster is defined as "a serious disruption of the functioning of a community or a society at any scale due to hazardous events interacting with conditions of exposure, vulnerability, and capacity, leading to one or more of the human, material, economic and environmental losses, and impact" (UNDRR, 2020). Hazardous events can be of biological, environmental, geological, hydrometeorological, or technological origins. The degree of interactions between vulnerable and exposed human and eco-system elements and the severity of hazards determines the likelihood of disasters and their impacts (Field et al., 2012). As demonstrated in Fig. 1, compared to the rest of the world, Asia and the Pacific region has high fatalities from multiple disasters, dominated by earthquakes (46%), followed by storms (37%) and floods (12%).

Vulnerability and exposure to hazards vary between the countries in the Asia Pacific region. These variations are due to the location, socio-economic status, development practices, cultural nuances, among many other factors. From the Asia region, countries such as Nepal, Cambodia, Pakistan, and Afghanistan have higher exposure and vulnerability index compared to developed countries such as Japan, Singapore, and the Republic of Korea (UNESCAP, 2019).

As described in Fig. 2, Average Annual Economic Losses are over US$ 675 billion in the Asia Pacific region. Of which, drought is accounting for 60% of the average annual losses while earthquakes reports 13.6%, tropical cyclone reports 12.8%, and floods account for 12.8% (UNESCAP, 2019). Hydrometeorological disasters such

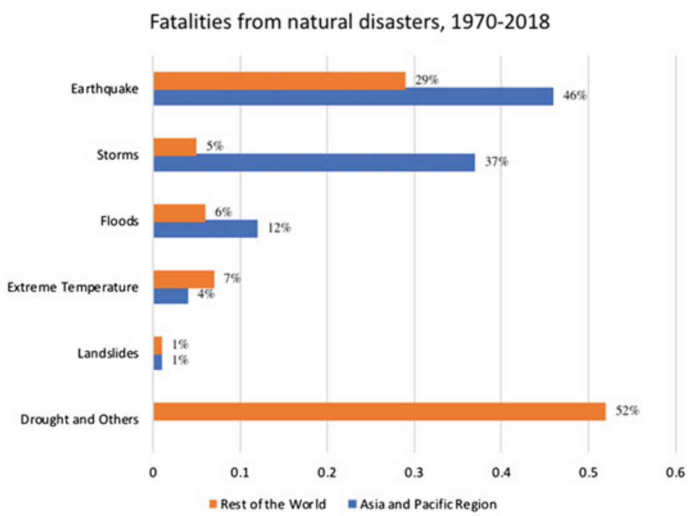

Fig. 1 Fatalities from natural disasters, 1970–2018. *Data source* (UNESCAP, 2019)

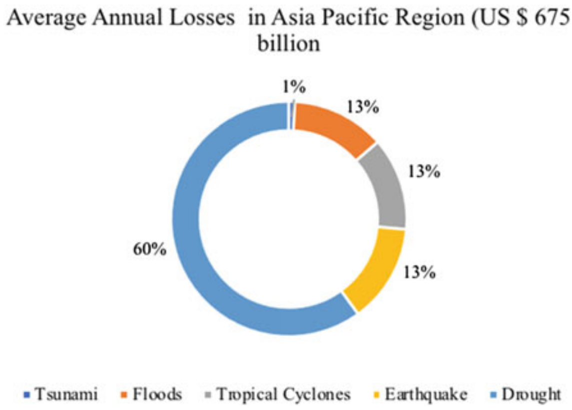

Fig. 2 Percentage of average annual losses in Asia Pacific Region. *Data source* (UNESCAP, 2019)

as droughts, tropical cyclones, and floods, which have direct linkages with climate change, account for more than 85.6% of the average annual economic losses. This highlights the nexus between climate change and development as climate-induced disasters have a high toll on the national economies in the region.

Based on the latest Asia Pacific Disaster Report published in 2019, the region shows clear increasing trends in the number of people affected by disasters and economic losses as a percentage of Gross Domestic Products (GDP) of the economies (UNESCAP, 2019).

Due to the enhanced early warning and other disaster preparedness actions, fatalities across the region and the rest of the world have recorded a decreasing trend, as demonstrated in Fig. 3.

Although fatalities from disasters are reducing both in Asia and other regions of the world, the number of people affected during the last five decades in the Asia Pacific region is increasing at an increasing rate compared to the rest of the world,

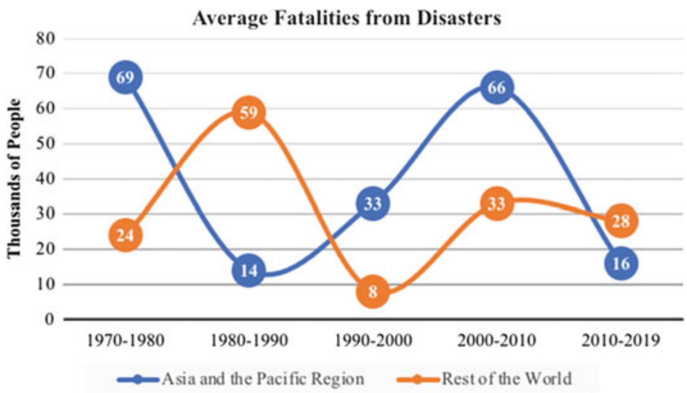

Fig. 3 Average deaths from disasters: 1970–2019. *Data source* (UNESCAP, 2019)

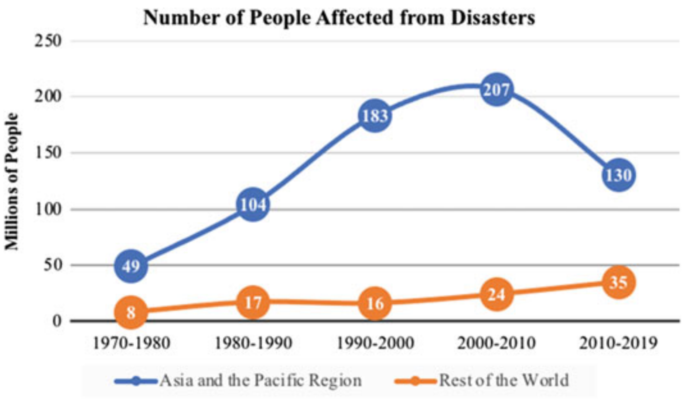

Fig. 4 Number of people affected by disasters: 1970–2019. *Data source* (UNESCAP, 2019)

as shown in Fig. 4. Economic losses as a percentage of the GDP have also shown a growing trend at an increasing rate compared to the rest of the world. These trends demonstrate the exposure, vulnerability, and fragility of the socio-economic system of the region and highlight the importance of urgent actions in addressing disaster risks.

The number of people affected during the last five decades in the Asia Pacific region is increasing at an increasing rate compared to the rest of the world. Economic losses as a percentage of the GDP have also shown a growing trend at an increasing rate compared to the rest of the world (UNESCAP, 2019). These trends demonstrate the exposure, vulnerability, and fragility of the socio-economic systems of the region and highlight the importance of urgent actions in addressing disaster risks in changing climates.

Asia region is highly exposed to climate change, therefore it hastens climate-induced hazards. Therefore the next section of the chapter discusses climate change and its nexus with disasters in the region.

3 Climate Change

Climate change is a trigger for extreme events. Climate change can increase frequencies and intensities of hydrometeorological events such as heatwaves, floods, droughts, wildfires, and tropical storms, resulting in substantial impacts and consequences to the communities and natural eco-systems (Smith et al., 2009). Global average temperature rise has reached 1.1 ± 0.1 °C in comparison to the pre-industrial level global mean average (WMO, 2018). With the current emission reduction commitments, global warming may increase 2–3 °C with a 50% probability, and it may raise up to 3–4 °C with 34% probability, compared to the pre-industrial global average (Fawcett et al., 2015). As shown in Fig. 5, it is evident that climate-induced

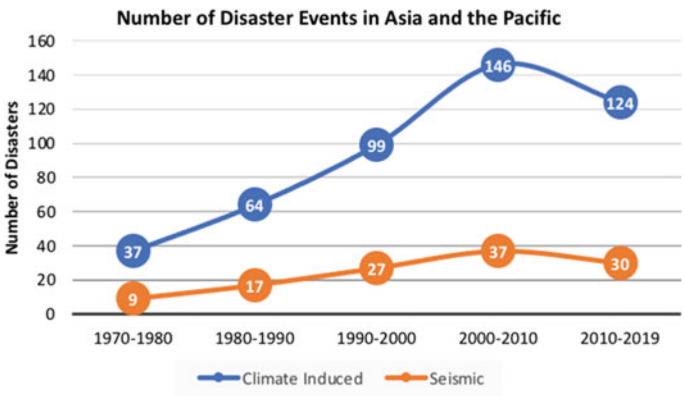

Fig. 5 Comparison between climate-induced and geological disaster events in Asia–Pacific Region-average per decade. *Data source* (UNESCAP, 2019)

disasters in Asia and the Pacific region are on the rise for the last five decades compared to geological disaster events for the same period.

As shown in Fig. 5, the correlation between climate change and hydrometeorological events is clear. However, climate change does not impact global communities equally. Its impacts are disproportionately based on the regions, countries, and population dynamics, resulting in benefits for some while negatively impacting others (Smith et al., 2009). Most of the countries in the Asia Pacific region are at the receiving ends than getting benefits from climate change. In the Central Asia subregion, the availability of water will be increased in the first half-century compared to the pre-industrial era resulting in more floods and then gradually decrease over the years (Reyer et al., 2017a). In the South Asia subregion, climate change will spark more tropical cyclones, changes in the rainfall and seasonal patterns, riverine floods, and river flows. These will results in floods, droughts and reduce agricultural production and yield losses (Vinke et al., 2017).

Development pathways and choices that communities, countries, and regions make will determine the extent of impacts from climate change faced by the future generations (Field et al., 2012). Authors suggest that lessons learned and experience in adapting to climate-induced extreme events provide valuable insights and ways forward in tackling the current and future climate risks.

While climate change and climate-induced disasters have widespread socio-economic impacts on the at-risk communities in the region, one of the highly vulnerable key sectors is food security. It impacts the availability, affordability, and access to nutritious foods. Therefore the next section of the chapter discusses food security and its nexus with climate change impacts and disasters.

4 Food Security

"Food security can be defined as a condition where all people at all times have economic and physical access to sufficient safe and nutritious food to meet their dietary needs and food preferences for a healthy and active life" (FAO, 1996). Although the early definition of food security focused on physical availability and national food self-sufficiency, the FAO declaration in 1996 added additional attributes to go beyond the physical quantity. Disaster risk reduction is a prerequisite and strongly interconnected with alleviating poverty and hunger (FAO, 2013). Most of the poor and food unsecured people live in developing countries and in rural areas. Poverty, Geographic dynamics, and highly undernourished populations in these countries are vulnerable to climate change, amplified by the nature of livelihoods, food availability, and affordability (Kaur & Kaur, 2016). Food crises and food insecurities are on the increasing path since 1980 due to adverse weather conditions, natural hazards, economic shocks, conflicts, and their combinations (FAO, 2013). Floods, tropical cyclones, and other extreme events cause damages and losses to the Agriculture infrastructure, assets, crops, inputs, and productivity. Damage and losses in the Agriculture sector impact food safety, quality and food and nutrition security (FAO, 2013).

As Asia is considered as the rice bowl of the word and a key player in global food security and supply chain, the next section of the chapter discusses the food security issues in Asia, compounded by disasters and climate change.

4.1 Food Security in Asia

The largest number of poor and food-insecure people live in Asia, compared to the rest of the world (Jayasuriya et al., 2013). Agriculture and food production, which largely depended on the climate and weather in the region, has been challenged by productivity changes, water scarcity, and drought (Kumar, 2016). Heat and water stresses in the region reduce crop growth and yields. Extreme events such as floods and cyclone storms can cause severe damages and losses to the harvests and infrastructure. Climate variations affect soil moisture and soil quality (May et al., 2015). Increased sea-level rise also reduces the available arable land in the region. South Asian countries are most vulnerable and exposed to Global Climate Change, although their greenhouse gas emission is relatively low. In a study conducted by Bandara and Cai (2014), they have established strong evidence to show the nexus between production changes in the Agriculture sector in South Asia and extreme weather events such as frequent and more severe floods and droughts. Severe food shortage and insecurity will occur by the year 2040 due to climate-induced productivity and production changes (Cai et al., 2016). They also highlight that it will also impact the GDP in the countries of the region as the Agriculture sector contribution is significantly high to the national GDPs of the South Asian countries. Densely populated countries such as China and India will have substantial impacts on GDP due to climate change from 2016 to 2035 (Chen et al., 2020).

South Asia's food security is centered around three main crop types, which are rice, wheat, and other cereals. It is projected that per person, global food availability will be reduced by 3.2%, while fruit and vegetable consumption will be reduced by 4% (Springmann et al., 2016). According to their study, food availability and consumption changes due to climate change are subject to regional variations. As Asia is highly exposed to climate change, reduction of food availability in low and middle-income countries of the Southeast Asia region is projected at 4.1%. Southeast Asia is one of the most rice-producing and consuming regions of the world. Rice yield will be reduced from 15 to 45% by 2080 due to climate change in Southeast Asia, namely Thailand, Vietnam, Laos, Cambodia, and Myanmar (Chun et al., 2016). This will impact not only the food prices but also food security as it will impact the physical and economic access to safe and nutritious food by people in the South Asian countries. These impacts can further be amplified due to the physical damage and monetary losses caused by climate-induced extreme events and disasters. The highest food inflation will be in Nepal, followed by Bangladesh and India in 2030 (Bandara & Cai, 2014). Authors further argue that Pakistan will be having relatively low food price inflation while Sri Lanka has the lowest food price inflation by 2030 compared to the South Asia baseline. Food price inflation will impact food intake and food security in Asia due to climate change.

Food security cannot be achieved in a single policy or action in isolation as it has multitudes of connections with climate change, disasters, and development paradigms, as discussed earlier in this chapter. It requires an integrated approach and collective actions by multiple stakeholders. Therefore next section of the chapter discusses the need for a coherence approach for food security in Asia. It also discusses the global frameworks related to climate change, disaster risk reduction and development, and their inter-linkages at policy, strategy, and program levels.

5 Coherence Approach for Food Security in Changing Climates and Disasters in Asia

As discussed in this chapter, climate change, extreme events, and food insecurity have strong nexus and interdependencies. Therefore addressing these issues cannot be done in isolation. As shown in Fig. 6, it requires coherence in assessing the risks and developing policies, strategies, and programs in an integrated manner, specifically at the national, sub-national, and local levels. The national, sub-national, and local strategies and actions should be developed by adopting relevant global frameworks related to sustainable development, food security, climate change, and disaster risk management. As shown in Fig. 7, the main global frameworks include;

1. Sustainable Development Goals (SDGs): 2015–2030
2. Sendai Framework for Disaster Risk Reduction (SFDRR): 2015–2030
3. The Paris Agreement on Climate Change: 2015.

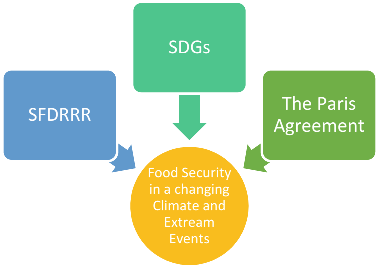

Fig. 6 Coherence of global frameworks for food security in a changing climate and extreme events

Fig. 7 Sustainable development goals

6 Sustainable Development Goals

Sustainable Development Goals (SDGs) or commonly referred to as the post-2015 development agenda, were adopted by UN member states as the blueprint to strategize development priorities, goals, and targets to be achieved by 2030 (UNDESA, 2020). It has identified seventeen goals. Climate change and disasters have direct nexus on the achievability of the SDGs. Among the seventeen goals, specifically Goal Number 1: No Poverty; Goal Number 2: Zero Hunger; Goal Number 3: Good Health and Well-being; Goal Number 6: Clean Water and Sanitation; Goal Number 7: Affordable and Clean Energy; Goal Number 8: Decent Work and Economic Growth; Goal Number 11: Sustainable Cities and Communities; Goal Number 14: Life below Water and Goal Number: 15 Life on Land have direct impacts and links with the climate change and disasters.

Both climate change and climate-induced disasters will delay the progress of achieving SDG targets by 2030. Climate Actions have been given a priority in the SDGs (Goal Number 13) to achieve time-bound targets by the member states. Goal 13 urges the member states to “take urgent actions to combat climate change and its impacts” (UNDESA, 2020). The framework reports that 2019 was the second warmest year on record, and the global mean temperature is projected to rise by 3.2 °C in 2100. Due to the current and future climate change, the frequency and severity of disasters such as wildfires, droughts, hurricanes, and floods will continue to rise, affecting more than 30 million people in 2018 (UNDESA, 2020). Therefore prioritizing climate actions in an integrated manner, as stated in the SDG, is a timely need to enhance resilience and food security in the Asia region.

Goal 2, “Zero Hunger aims to end hunger, achieve food security and improved nutrition, and promote sustainable Agriculture” (UNDESA, 2020). Food insecurity was increasing before the global COVID-19 pandemic. The UNDESA (2020) says the population affected by moderate to severe food insecurity was 23.2% in 2014, whereas it has increased up 26.4% by 2018. Climate change, COVID-19 pandemic, locust crisis, and climate shocks will continue to increase food insecurity globally and in Asia. Small scale farmers are highly vulnerable to climate shocks and crises, and 40–80% of food producers are living in developing regions such as Asia (UNDESA, 2020).

7 Sendai Framework for Disaster Risk Reduction

Sendai Framework for Disaster Risk Reduction (SFDRR: 2015–2030) is the global blueprint for reducing disaster risk across the world. The outcome of the SFDRR for the next 15 years is “the substantial reduction of disaster risk and losses in lives, livelihoods, and health and in the economic, physical, social, cultural and environmental assets of persons, businesses, communities and countries” (UNISDR, 2015). As shown in Fig. 8, the framework has identified four priority areas for actions to invest in disaster risk reduction.

Countries develop their national and sub-national strategies for disaster risk reduction adopting the priorities of SFDRR. However, by 2019 only 85 countries have developed National Disaster Risk Reduction Strategies in line with Sendai Framework for DRR (UNDESA, 2020). Climate change adaptation has to be considered across all four priorities of the SFDRR. Integrating climate change adaption into the risk assessment processes, disaster risk governance, risk reduction for resilience, and disaster preparedness is a prerequisite. Without such an integrated approach, countries in the Asia region will not be able to achieve SDGs, food security, and resilience.

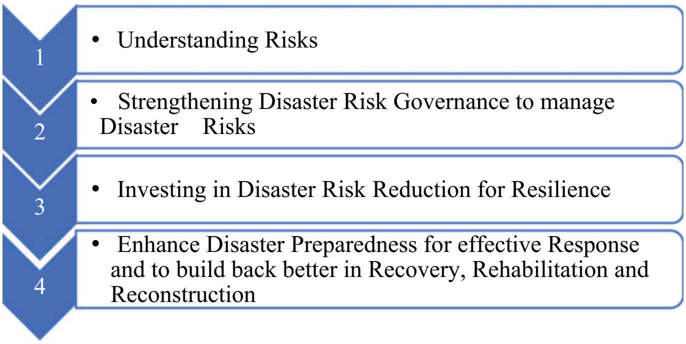

Fig. 8 Sendai framework of action priorities

8 The Paris Agreement on Climate Change

Building upon past efforts, the Paris Agreement was adopted in 2015 as the global blueprint for climate actions, which mobilizes all nations into a common framework to commit and undertake efforts to mitigate climate change and adapt to its direct and indirect effects while supporting the developing nations to make substantial contributions in mitigating efforts (UNFCCC, 2020). The agreement has recognized that developing countries are more vulnerable to the adverse effects of climate change. Further, the agreement has established clear nexus between climate change actions, responses, and impacts with sustainable development and poverty alleviation. It has also established nexus, supported by scientific evidence, with food security, and ending hunger, especially in vulnerable countries to the climate change impacts (UNFCCC, 2020).

The agreement also recognizes the need for adaptation and enhancing adaptive capacity, strengthening diester resilience and reducing vulnerabilities to climate change within the context of sustainable development and SDGs. The framework also recognizes the need for having locally-driven country-specific adaptation strategies following an integrated approach in socio-economic policies, strategies, and programs. It also supports disaster risk reduction within the sustainable development framework through addressing loss and damage resulting from extreme weather and slow onset events. Specifically, as shown in Fig. 9, the agreement supports priority disaster risk reeducation measures of SFDRR 2015–2030.

Food Security is a common link in all three global frameworks, as shown in Fig. 10.

Achieving no-poverty, zero hunger, good health and wellbeing, sustainable cities and communities, responsible production and consumption, and climate actions are pre-requisite for food security. On the other hand, food insecurity will impact the progress of achieving the above-stated goals of the SDG. Besides, priory actions of the Paris Agreement, i.e., Early Warning System, Emergency Preparedness, risk reduction for slow-onset events such as droughts, comprehensive risk assessment including

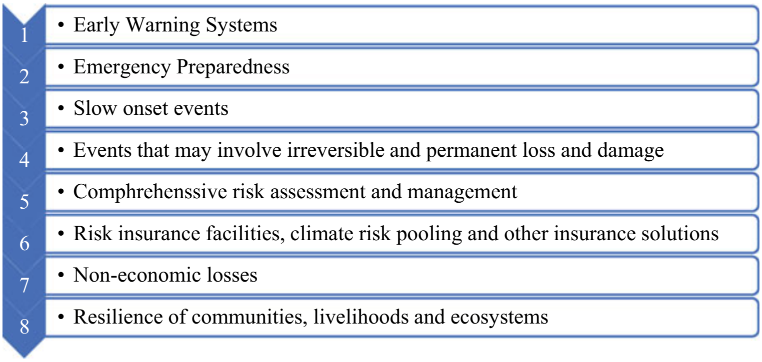

Fig. 9 Climate adaptation and risk reduction measures of the Paris agreement

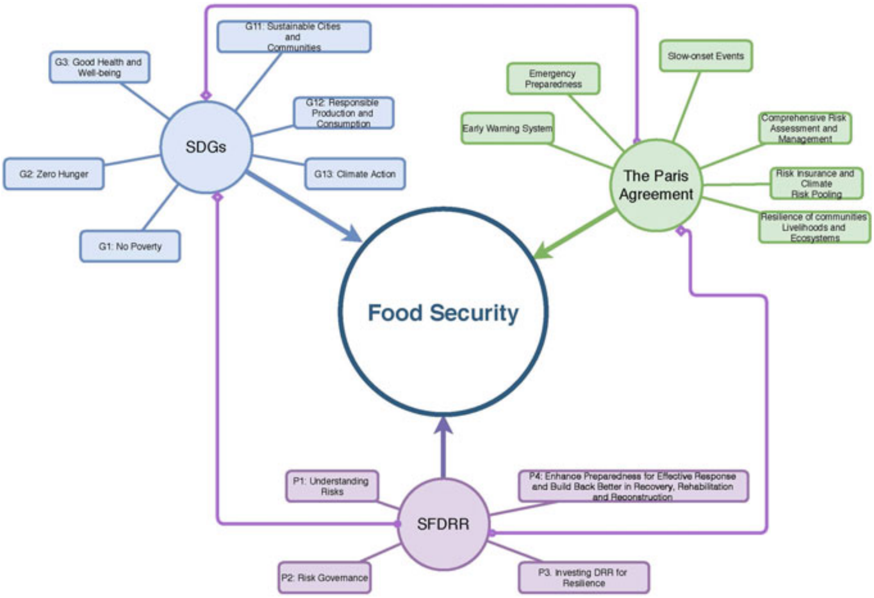

Fig. 10 Food security Nexus of SDGs, the Paris agreement and SFDRR

access to food and food security, risk insurance and risk transfer mechanisms and resilience of livelihoods and ecosystem will lead to food secured communities and nations. In contrast, failure to take action will eventually contribute to food insecurity, malnutrition, and hunger among the at-risk communities. Food and livelihood security is a key component across the SFDRR. Assessing the risks, preparing emergency stockpiles, and food access and availability, investing in resilience including in food production and productivity, are key priority targets of the Sendai Framework for DRR and its national frameworks. Figure 10 shows common and related actions of the SFDRR, SDGs, and the Paris Agreement, which require investments leading toward 2030 by the policymakers and practitioners at the national, sub-national, and local levels to create food secured communities in a changing climate. Food security is one of the key outcomes of collective and coherent actions by all three global frameworks and can be considered as the glue to keep the frameworks together at the local level.

9 Discussion

It is evident that all regions, including Asia, will be having climate change impacts even if we limited global warming in between 1.5 and 2.0 °C above the pre-industrial level. If global warming goes beyond 4.0 °C compared to the pre-industrial average level, severe consequences in terms of extreme events may occur. It will be a significant setback to human development and poverty eradication (Reyer et al., 2017b). Complex interlinkages between climate change and hazards have been discussed in multiple studies. It has revealed beyond a reasonable doubt that climate change will increase the intensity, frequency, and magnitude of hazards. Asia region faces a high degree of vulnerability to climate change. This also supports the findings of previous studies, which had concluded that substantial impacts on the production losses are expected by 2030 due to climate change in selected countries of Asia (Bandara & Cai, 2014).

As the frequency, magnitude, and intensity of hazards will increase due to climate change, their direct and indirect impacts on food production, productivity, availability, and access will be a major challenge in the twenty-first century. Therefore coherent and integrated policies, strategies, and programs are required to meet the challenge. This also supports the previous study findings (Jayasuriya et al., 2013) which suggested that government policies and interventions through enabling environments are required to help reduce the major increase in food insecurity in Asia. The sharp price increase can lead to a lack of access to food and thereby lead to food insecurity.

Communities in the region need to adapt to the prevailing and future climate change scenarios. That includes, but not limited to, assessing risks and vulnerabilities and investing in risk reduction, including adopting resilient livelihoods and Agriculture. Climate Change Adaptation is a necessary instrument for ensuring food security in the region (Cai et al., 2016). Asia has shown some resilience to a sharp price surge without significant impacts on food security compared to other regions through emergency measures (both market and food stocks). This could be a short-term condition. Therefore it should not be taken for granted. Long-term investment in resilience is a priority from the development, climate actions, and DRR agendas. This argument has been supported by previous studies, which had concluded that investing in long-term food security is a priority in a changing climate (Jayasuriya et al., 2013).

One of the key goals of the SDGs is to alleviate poverty, and thereby increasing the growth and food security in the region by 2030. The success of those strategies depends on a wider range of actors, including local governments, farmer organizations, civil society groups, and individuals. Improved awareness among broader communities on climate change impacts on the food security sector is vital to ensure successful adaptation and engagement of wider stakeholders (Cai et al., 2016). Contribution to knowledge, sharing good practices, and lessons learned are important instruments for integrated and coherent actions for disaster risk reduction and climate change adaptation and thereby ensuring food security. Previous studies have also recognized that the value of co-creation and co-production of knowledge, practices, and skills from multiple sectors and regions are required to better understand the complex relationships between climate change and development (Reyer et al., 2017b).

10 Conclusion

It is evident from the chapter that climate change and climate-induced disasters will derail the economic growth and targets set in the SDGs, specifically in low and middle-income countries in Asia. Among them, food security of the at-risk communities will be challenged by multiple fronts such as production and productivity loses and direct and indirect damage and losses on the Agriculture sector, including Agro-infrastructure, due to climate-induced disasters.

Extreme events and climate wonders can exceed the coping capacities of the countries and emergency food stocks, which may lead to long-term price surge and food insecurity. This is concerning as 2030 has been identified as a key milestone of the global frameworks such as SDGs, SFDRR, and the Paris Agreement on Climate Change. If urgent and inclusive adaptation strategies, policies, and programs are not developed and implemented, targets set to achieve by 2030 will not be within our reach.

Food security is a common concern for the development, climate change adaption, and disaster risk management communities. Therefore it can be considered as a common entry point for integrated and coherent actions, supporting the implementation of SDGs, SFDRR, and the Paris Agreement. Taking the lead from global blueprints, enabling policies, strategies, and programs are required in the Asian countries to address food security issues in a changing climate and extreme events. Coherent policies and programs should be developed by adopting global frameworks in an integrated manner than in isolation. However, most of the countries in Asia, if not all, are yet to implement coherent strategies and actions, taking into consideration the common priorities of SDGs, SFDRR, and the Paris Agreement from the food security lens.

The nexus between climate change, disasters, development, and food security is complex and interconnected. Although previous researchers have established relations between them, further studies and context-specific analytics are required to unpin the complexities with regard to hazard nexus and their scales, impact nexus, and their magnitudes, and solution nexus and their approaches. Such knowledge will ultimately contribute and support sustainable development in the backdrop of changing climate and more frequent and severe disasters in Asia. Further, research and sharing good practices and case studies on coherence in applying global frameworks such as SFDRR, SDGs, and the Paris Agreements in an integrated manner at national, sub-national, and local levels will enhance the resilience, sustainable development, and food security in Asia.

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The Role and Challenges for Local Governments in Achieving the Resilience of Critical Infrastructure

E. Gencer, A. Panda, and Dilanthi Amaratunga

Abstract The availability of robust and resilient infrastructure influences the sustainable and resilient development of cities and territories. This paper examined the role of local governments in addressing resilience of critical infrastructure and the barriers that they face in doing that. It positions the concept of resilient infrastructure within the context of the Sendai Framework for Disaster Risk Reduction 2015–2030 (SFDRR), and its localization through the *Making Cities Resilient Campaign.* The paper examines some of the barriers and challenges in updating and/or building resilient infrastructure at the local level. Among the challenges, the paper examines those that derive from interdependencies, ownership complexities, lack of incentives and particularly those that are rising from inadequate powers of local governments. In conclusion, the paper brings all the discussions together to address lessons learned and provide recommendations for local governments to address the challenges to increase the resilience of critical infrastructure in their cities and territories.

1 The Role of Critical Infrastructure in Addressing Resilience at the Local Level

Modern society is heavily dependent on the effective and efficient operation of critical infrastructure systems to deliver public services, enrich living standards and stimulate economic growth. Robust and resilient infrastructure are key drivers of local and

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national economic growth. The reliability, performance, continuous operation, safety, maintenance, and protection of critical infrastructures are national and local priorities around the world. However, evidence shows that existing infrastructure systems are increasingly being affected by natural and man-made hazards, and from the impacts of climate change. A recent study by the UN Office for Disaster Risk Reduction (UNDRR, 2019a) has found that since 2005, on average, more than 3200 schools, over 412 health facilities, and 3200 km of roads have been damaged or destroyed each year in a baseline sample of extensive risk in 83 countries. The European Union (EU) estimates that "climate change related damage to infrastructure could grow tenfold under a business-as-usual case scenario" (UNDRR, 2020), and if infrastructure is made more resilient, these impacts can be reduced (ADB, 2019).

In addition to climate change, the risk drivers of urbanization and unsustainable investment decisions further increase the impact of hazards on infrastructure (UNDRR, 2020).This creates the need to enhance the resilience of infrastructure, and to specially emphasize its adaptation to changing climatic conditions over time (Rehak et al., 2019). Additionally, governments need to consider developing new resilient infrastructure systems to serve for the rapidly urbanizing areas, and particularly for the vulnerable populations living in informal settlements. Many governments, particularly local governments, are challenged to upgrade and maintain existing infrastructure to become more resilient and build new ones to provide for their increasing populations.

At the time of drafting this paper, the outbreak of a novel coronavirus disease (COVID-19) has gone from an initially discrete outbreak to a raging pandemic. The COVID-19 outbreak has now affected over 199 countries and territories. The most vulnerable, including the elderly, minority communities, informal and public service workers have been hit the hardest. Small and Medium Enterprises (SMEs), health infrastructure systems, essential services that are dependent on transport infrastructure are under tremendous duress. In the face of aggravating changing climate, pandemics such as Covid-19, and growing urbanization, infrastructure resilience is increasingly becoming important.

This paper examines the role of local governments in addressing resilient infrastructure and the barriers they face in undertaking this critical risk reduction and resilience building activity. The paper will first position the concept of resilient infrastructure within the context of the Sendai Framework for Disaster Risk Reduction 2015–2030 (SFDRR), and within different country contexts. It will then discuss the practice of localizing SFDRR through the *Making Cities Resilient Campaign*, and how it can help ensure adequate and resilient infrastructure at the local level. As a third step, the paper will examine some of the barriers and challenges in updating and/or building resilient infrastructure at the local level. Among the challenges, the paper will examine those that derive from interdependencies, ownership complexities, lack of incentives and particularly that are rising from inadequate powers of local governments. In conclusion, the paper will bring all the discussions together to address lessons learned and provide recommendations for local governments to address the challenges to increase the resilience of critical infrastructure in their cities and territories.

2 Positioning Critical Infrastructure Within the Context of the Sendai Framework for Disaster Risk Reduction 2015–2030 (SFDRR)

The Sendai Framework for Disaster Risk Reduction 2015–2030 (SFDRR) is the first of the 2030 Development Agendas, and the only Global Agenda that specifically deals with disaster risk reduction. The Sendai Framework aims for "the substantial reduction of disaster risks and losses in loves, livelihoods and health, and in the economic, physical, social, cultural and environmental assets of persons, businesses, communities and countries" by the year 2030 (UN, 2015). Adopted by the member states during the Third World Conference on Disaster Risk Reduction in Sendai, Japan in 2015, the Sendai Framework responds to risk generated from small-scale and large-scale, frequent and infrequent, sudden and slow-onset disasters, caused by natural or manmade hazards as well as related environmental, technological and biological hazards and risks. It aims to guide the multi-hazard management of disaster risk in development at all levels as well as within and across all sectors. To achieve its goals, the global agreement has put forward seven targets and four priority areas to reduce existing risk, to prevent new risk, and to build resilience (See Fig. 1).

Of the seven targets set out in the Sendai Framework, the 4th target (substantially reduce disaster damage to critical infrastructure and disruption of basic services, among them health and educational facilities, including through developing their resilience by 2030) is the most relevant to the issue of critical infrastructure resilience. At the same time, other targets of the framework, such as those that deal with the

Fig. 1 The seven targets of the Sendai framework for disaster risk reduction 2015–2030 (Courtesy of UNDRR)

reduction of mortality, affected populations and economic losses are also all dependent on the availability, efficiency, and the resilience of infrastructure systems. To achieve these 7 targets, the Sendai Framework proposes thirteen guiding principles within and across sectors by States at local, national, regional, and global levels in the four priority areas.

The Four Priority Areas of SFDRR are:

1. Understanding disaster risk.
2. Strengthening disaster risk governance to manage disaster risk.
3. Investing in disaster risk reduction for resilience.
4. Enhancing disaster preparedness for effective response and to "Build Back Better" in recovery, rehabilitation, and reconstruction.

In Priority 3, the Sendai Framework calls to maintain, upgrade, and build new infrastructure. It appeals to national and local governments to "strengthen disaster-resilient public and private investments, particularly through structural, non-structural and functional disaster risk prevention and reduction measures in critical facilities, in particular schools and hospitals and physical infrastructures; building better from the start to withstand hazards through proper design and construction, including the use of universal design and the standardization of building materials, retrofitting and rebuilding; nurturing a culture of maintenance" (UN, 2015). However, to ensure that investment in critical facilities are resilient, it would be of importance to equally understand risk (Priority 1),strengthen risk governance (Priority 2), and to ensure that post-disaster reconstruction actions consider the strengthening of infrastructure systems and building resilient new ones as part of the Building Back Better agenda (Priority 4).

2.1 Critical Infrastructure in Context

While the Sendai Framework primarily focuses on 'critical infrastructure', it also refrains from establishing a definition leaving it for the national governments to decide on elements that they would like to include when reporting on progress. On the other hand, the Framework mentions some infrastructure types, which it considers critical, namely: water, transportation and telecommunications infrastructure, educational facilities, hospitals, and other health facilities. To explore the challenges including those that relate to governance, it would be necessary to explore how the coverage of critical infrastructure is comprehended within different country contexts.

According to the Australian Government, critical infrastructure is defined as "those physical facilities, supply chains, information technologies and communication networks which, if destroyed, degraded or rendered unavailable for an extended period, would significantly impact the social or economic wellbeing of the nation or affect Australia's ability to conduct national defense and ensure national security" (ACIC, 2020).

The Government of South Africa, in its 2019 Gazette, classifies critical infrastructure as those whose "(a) functioning is essential for the economy, national security, public safety and the continuous provision of basic public services; and (b) the loss, damage, disruption or immobilization of such infrastructure may severely prejudice. (i) the functioning or stability of the Republic; (ii) the public interest regarding safety and the maintenance of law and order; and (iii) national security" (Gov.Sa, 2019).

In 2013, the United States Government defined critical infrastructure, "as systems and assets, whether physical or virtual, so vital to the United States that the incapacity or destruction of such systems and assets would have a debilitating impact on security, national economic security, national public health or safety, or any combination of those matters" (WH, 2013).

Germany's Federal Office for Information Security defines critical infrastructures as "organizational and physical structures and facilities of such vital importance to a nation's society and economy that their failure or degradation would result in sustained supply shortages, significant disruption of public safety and security, or other dramatic consequences," and lastly, the European Commission classifies critical infrastructure "…an asset, system or part thereof located in Member States which is essential for the maintenance of vital societal functions, health, safety, security, economic or social wellbeing of people, and the disruption or destruction of which would have a significant impact in a Member State as a result of the failure to maintain those functions" (BSI, 2020).

Physical or virtual assets, social and economic wellbeing, safety and security, health and continuity of public services are common across the above definition that form the basis for any measures that would address resilience of interconnected and interdependent infrastructure. These measures need to equally strengthen the ability to resist, absorb, accommodate, adapt to, transform, and recover from the effects of any hazard in a timely and efficient manner, through engagement, adequate capacity, and risk informed governance.

3 Localizing the Sendai Framework Through the Making Cities Resilient Campaign and Achieving the Resilience of Critical Infrastructure at the Local Level

The Sendai Framework gives special importance to the role of local level action to achieve its goals and ensure the development of resilience cities and communities. Indeed, SFDRR's Target E calls for the increase in countries with local DRR strategies. There are also clear action points for local and sub-national governments within all SFDRR Priorities of Action. On the other hand, the Sendai Framework also recognizes the challenges local and sub-national authorities face in order to undertake these risk reduction and resilience building actions. Therefore, as one of

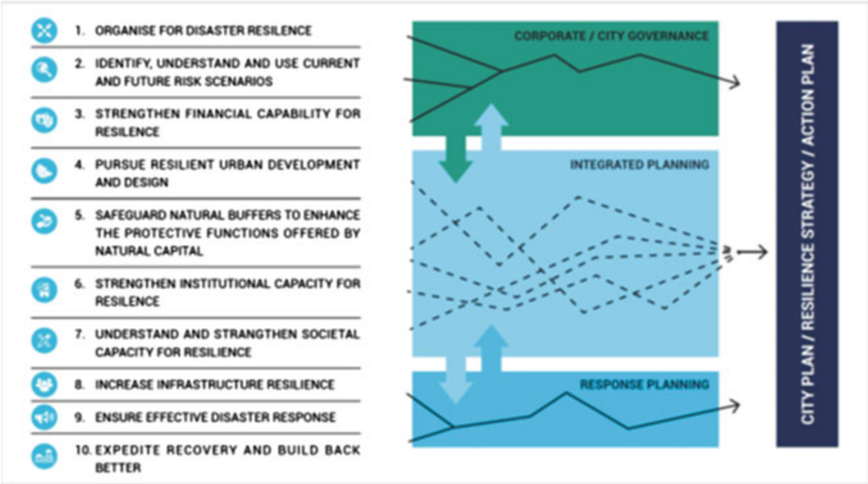

Fig. 2 The new ten essentials for making cities resilient (UNISDR, 2017)

its thirteen guiding principles, the Sendai Framework calls for the "empowerment of local authorities and communities through resources, incentives and decision-making responsibilities as appropriate" (UN, 2015).

To support the implementation of the Sendai Framework at the local/urban level, UNDRR with its partners have developed a set of key principles as part of the *Making Cities Resilient Campaign*. The Ten Essentials for Making Cities Resilient along with the Disaster Resilience Scorecard supported the implementation of the Sendai Framework at local level. As of June 2020, over 4000 cities have joined the *Making Cities Resilient Campaign* and many of them have started adapting the Ten Essentials and undertaking Resilience Scorecards to understand their state of resilience and measure their progress in risk reduction and resilience building (See Fig. 2).

One of the Ten Essentials, Essential 8, specifically focuses on the importance of increasing Infrastructure Resilience at local level. Essential 8 calls for local governments to "address the capacity and adequacy of critical infrastructure and develop a plan or strategy for its protection, update and maintenance" (UNISDR, 2017; Panda & Amaratunga, 2019). According to Essential 8, where needed local governments should ensure to develop, protective, risk mitigating infrastructure. The Ten Essentials and the Disaster Resilience Scorecard provide local governments with detailed indicators to understand their current level of resilience as a baseline and guidance for how to increase their infrastructure resilience.

The Ten Essentials (UNISDR, 2017) calls for local governments to address resilient infrastructure through the following actions:

How to Increase Infrastructure Resilient at Local Level:

1. Prepare and implement a critical infrastructure plan or strategy to protect critical infrastructure, utilities, and services
   - Promote a shared understanding of the risks between the city and various utility providers of the points of stress on infrastructure systems and risks at the city scale.
   - Maintain appropriate building codes, regulations and continuity arrangements that aid the construction of critical infrastructure in low risk areas.
   - Manage continuity plans for the provision of critical services.
   - Sufficiently invest in the maintenance and upgrade of critical infrastructure.
2. Ensure that protective/risk mitigating infrastructure (e.g. flood defenses, seismic designs) is in place where needed and are properly maintained.
   - Supervise to ensure that existing, protective infrastructure is well-designed and well-built, based on risk information.
   - Administer processes that maintain protective infrastructure and ensure the integrity and operability of critical assets.
   - Create a comprehensive inventory or map of all critical infrastructure located within city limits.
   - Have policies in place to enable the monitoring, maintenance, and upgrade of drainage infrastructure (considering climate change).

Source: UNISDR (2017). How to Make Cities More Resilient: A Handbook for Local Government Leaders. UNISDR: Geneva.

Local governments can use these strategies to plan for infrastructure resilience; to build, upgrade, maintain or adapt them to increase the resilience of their communities. However, research indicates that many local governments are falling behind in addressing this DRR and resilience action. Indeed, in a recent overview of 214 cities that have taken Disaster Resilience Scorecard Assessments, it was found that only 17% of the surveyed cities "own and implement a critical infrastructure plan highlighting risks and continuity plans for essential infrastructure, services, and utilities;" and only 26% of the surveyed cities have a forum to establish a shared understanding of risks between the city and various utility providers, while 11% of them do not have any plans or forum (See Fig. 3) (UNDRR, 2019b).

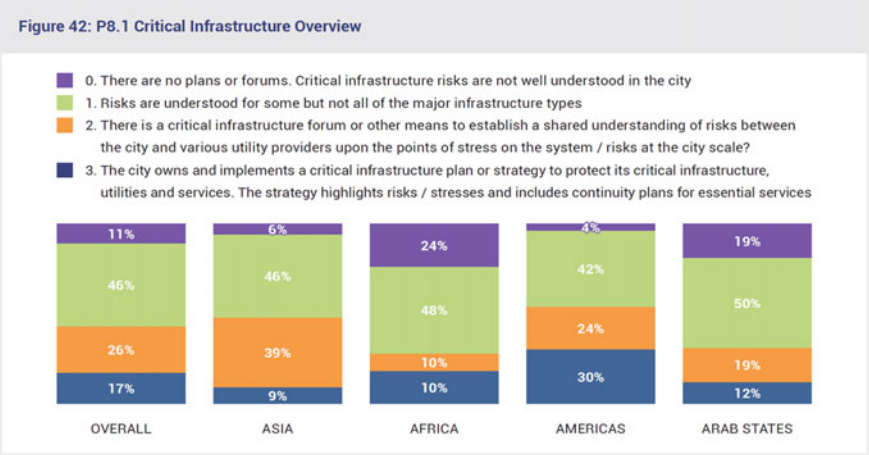

Fig. 3 How cities approach critical infrastructure *Source* UNDRR (2019b). Making Cities Resilient Report 2019: a snapshot of how local governments progress in reducing disaster risks in alignment with the Sendai Framework for Disaster Risk Reduction

As this study shows, despite the importance of critical infrastructure for achieving resilient cities and territories, local governments lack behind taking actions and ensuring its adequacy and resilience. The following section will explore some of the most commonly faced challenges local authorities face in achieving the resilience of critical infrastructure in their cities and territories.

4 Barriers for Achieving the Resilience of Critical Infrastructure at the Local Level

High population densities in cities, and the increasing interconnectedness of the services and supply chains that sustain them increase the challenges to effectively address the resilience of critical infrastructure at the local level. According to Lee (2019, 6), “the management of disaster facilities by local governments means regular maintenance and management of disaster-prone areas and hazardous facilities that are vulnerable to disaster. And, the resource access infrastructure of local governments facilitates the transport and input of human and physical resources necessary for disaster response and recovery.”

In a briefing done by UNDRR’s private sector network, ARISE, on the relationship between critical infrastructure and disaster resilience, it is stated that the resilience of critical infrastructure becomes a complicated issue due to several factors. Accordingly, one of the barriers is that critical infrastructure functions as an interrelated "systems of systems," and each system may interact with others and possesses interdependencies (UNISDR & ARISE, 2017). Another barrier is the diversified ownership of the assets within the critical infrastructure which makes the resilience of critical infrastructure a multi organizational endeavor (Rehak et al., 2019).

Indeed, having adequate powers to ensure critical infrastructure resilience in their cities and territories is a general concern of local and sub-national governments. In a study by UNISDR and the Center for Urban Disaster Risk Reduction and Resilience (CUDRR+R) that examined the authorities, capacities and responsibilities of local governments to undertake disaster risk reduction activities, it was found that out of the 151 participating cities to the study, only 44% of them stated to have legal authority for critical infrastructure planning, and to access and build data in order to do such planning in their cities (UNISDR and CUDRR+R 2017) (See Fig. 4). In addition, only 38% of the local governments in the study stated to have authority to develop and control budgeting for critical infrastructure planning, correlating with their responsibility levels. Due to the fragmented nature of critical infrastructure ownership, only 31% of the local governments own or operate relevant assets in this regard.

These barriers are further elaborated in the following section with a special focus on governance challenges.

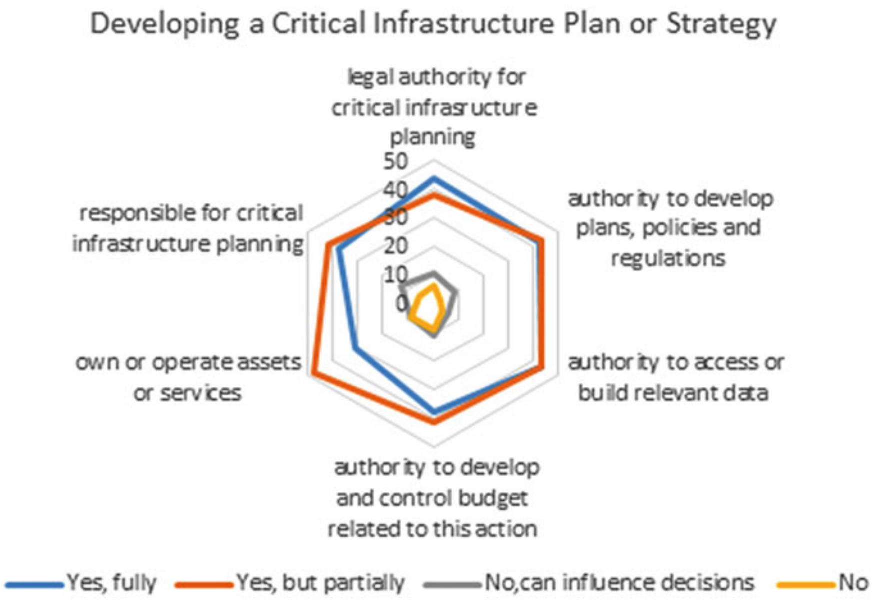

Fig. 4 Local government authorities, capacities, and responsibilities to develop critical infrastructure plans or strategies for resilience (%) (UNISDR and CUDRR+R 2017)

4.1 Understanding Dependencies and Connectedness

In handling the critical infrastructure resilience, one of the main barriers is the connectivity within and between them, which makes these systems interdependent and vulnerable to cascading failures (Heinimann & Hatfield, 2017). Various critical infrastructure sectors are so interconnected and interdependent that disruption of one asset can impair the efficiency of several other critical infrastructures. This is evident from the 2011 Great East Japan that affected over 8.9 million households from 15 prefectures lost electric power, 2.2 million lost water, and 459,000 lost city gas supply (Nojima, 2012). The cyber-attack in December 2015 on three Ukrainian energy distribution companies resulted in electricity outages for approximately 225,000 customers across the Ivano-Frankivsk region of Western Ukraine. The 2005 Hurricane Katrina in the United States completely paralyzed New Orleans, Louisiana and severely affected several states; and in 2012, power grids that failed in India resulted in blackouts through most of the northern and north-eastern states in the country. The blackouts and their crippling effects on the other critical infrastructures affected the lives of approximately six hundred million people (Singh et al., 2014).

It is frequently highlighted that the absence of adequate details regarding these interconnectedness and interdependencies, mainly due to the lack of experience and records of past events, have become a major challenge in addressing the resilience of critical infrastructure (Chang et al., 2014). Realizing the nature of system interdependencies and evolving vulnerabilities will play a vital role in dealing with the probabilities and consequences of cascading failures in interdependent systems especially in the design phase of resilient infrastructures (Vespignani, 2010). The scale of systemic risk stemming from increasing vulnerability to infrastructure systems at national or local levels is still not fully embedded (UNDRR, 2020). As suggested by Panda and Bower (2020), it is necessary to conduct a holistic risk assessment that takes into account all possible scenarios, hazards and vulnerabilities, their direct and indirect impacts, and exposure and awareness of potential sources as the basis for reducing risk from natural and technological risks.

4.2 Ownership Complexities

The existence of multiple stakeholders that own or operate critical infrastructure and provide associated services is one of the main challenges in developing the resilience of critical infrastructure. The barriers to cross-agency collaboration include differences in organizational goals, professional cultures, lines of accountability, political control styles and decision-making cycles. To complicate matters, many of the organizations involved in crisis planning involve actors in the voluntary and private sectors. In addition, organizational readiness through staff training and crisis exercises can be expensive and time consuming. Investing resources to plan for a multitude of extreme events that may never happen is hard to convince local government leaders and decision-makers, particularly in a time of budget constraints.

Other organizational factors such as cultural complacency, resource limitations, and shifting priorities conspire to derail or dead-end a crisis plan (Boin & McConnell, 2007). In a study on the relationship between local ownership of assets and community resiliency, it was found that the potential for community resilience depends upon the composition, type, and extent of ownership, and of the level of control associated with ownership (Varghese et. al., 2006).

According to UNDRR (2020), lack of clarity in ownership is a critical barrier to ensure compliance. Moreover, the fragmented nature of today's infrastructure landscape adds to the complexity. As national and local governments are trying to fill the financing needs for upgrading and/or building new critical infrastructure, they are frequently establishing new types of ownership.

5 Lack of Incentives for Resilience Measures

In a recent report on addressing infrastructure resilience, UNDRR (2020) has highlighted that "investment decisions rarely take into account the level of risk exposure in those locations, and opportunities for short-term profits continue to outweigh concerns about sustainability." Investing in resilience reaps its harvest mostly in the long run which is discouraging for many stakeholders (CISL, 2016). Therefore, it is necessary to provide additional incentives and enablers to improve active participation in disaster resilience investments (CISL, 2016; National Academies of Sciences et al., 2017; Watson et al., 2015).

In most countries, a considerable part of the critical infrastructure is, directly or indirectly, controlled and operated by the private sector. This implies that the development, upgrading, and maintenance of infrastructure are responsibilities of the private sector. However, governments typically bear responsibility for the consequences when infrastructure breakdowns.

Most critical infrastructure projects are often high profile, high value, and politically important. For them to be effective, efficient, and resilient, their operators and owners need extra incentives. Such incentives will help private sector to invest in changing management structures, practices, and cultures to anticipate, mitigate, and plan for breakdowns, as well as their societal consequences (Boin & McConnell, 2007). At the community and regional levels, local government budgets and expenditures are severely stretched to meet the economic and social demands of their communities. Local and regional governments must also be convinced to invest in co-benefits, bankability, and pipeline of infrastructure projects that are supported by partnership between the public and the private sector (UNDRR, 2020).

5.1 Governance Challenges

As it is discussed in the previous section, a large part of the responsibility for the resilience of critical infrastructure lies with the owners and operators. However, government departments, the devolved administrations, agencies, and regulators play an important part in ensuring that policies are in place and complied with, and that investment in infrastructure considers the needs for security and resilience (NIC, 2019). Local governments who are at the forefront of dealing with disasters have a major role to play in developing the resilience of critical infrastructure as well as ensuring the adequacy of risk mitigating infrastructure in their communities.

According to the UN Office for Disaster Risk Reduction (UNDRR, 2019c), "a strong governance system is characterized by laws and policies, institutions and coordination mechanisms, strong leadership, clear roles and responsibility, resources, monitoring and accountability set up across all sectors, all actors and all level." Institutional resilience will ensure connectedness of the various units of government at times of disruption, the cost and quality of services delivered in relation to the resources collected from the citizens, the strength of the government's mandate to act on the citizens' behalf, government's capacity to institutionalize and adapt lessons learned, and the extent of discretionary authority granted to government officials during a crisis, as well as political fragmentation and the percent of municipal expenditures for fire, police, and medical services (Cutter et al., 2010).

On the other hand, the governance of critical infrastructures involves considerable challenges: it overarches different, often fragmented, policy domains and territories and institutionally unbundled utility domains. Effective governance of critical infrastructures requires more regulatory efforts by national policies. At the same time, there is a need for identifying and assessing place-based vulnerabilities, for defining locally differentiated mitigation and preparedness strategies, and for the training of local utility companies, particularly for crisis management (Monstadt & Schmidt, 2019). In this setting the local government authorities have a vital role to play in handling critical infrastructure and their resilience.

On the other hand, in line with the context-based understanding of critical infrastructure, there are also regional differences in the authorities and capacities of local governments to address this issue. For instance, according to the previously mentioned UNISDR and CUDRR+R study, among all regions, local governments in Europe have the least powers (authority and capacities) for critical infrastructure resilience, with 32% of having no powers and 36% reporting to have no responsibilities for this action. Whereas local governments in the Americas reported to have high level of authority and capacities (88% of them) and responsibilities (86% of them), fully and partially, to develop a critical infrastructure plan or strategy for their respective administrative areas (See Figs. 5 and 6) (UNISDR and CUDRR+R 2017).

Gaps in governance will lead to obstacles in achieving resilient critical infrastructure, insofar as no planning or regulatory agencies address the collective resilience of independent infrastructure systems. Such obstacles are made even worse by situations involving cross-border infrastructure systems, such as power grids (McDaniels et al.,

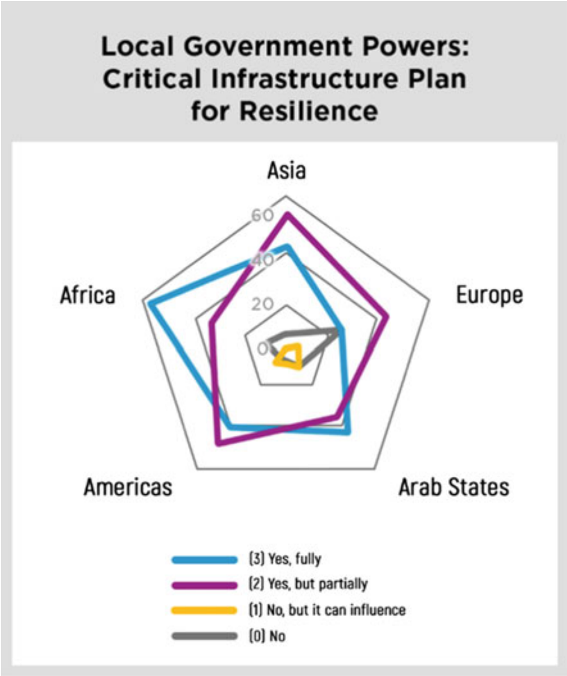

Fig. 5 Regional distribution of local government powers (authorities and capacities) to develop a critical infrastructure plan or strategy for resilience (%) (UNISDR and CUDRR+R 2017)

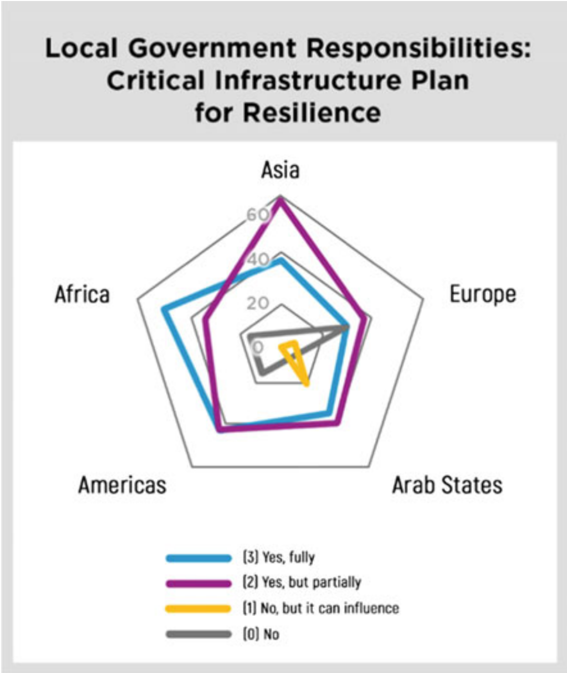

Fig. 6 Regional distribution of local government responsibilities to develop a critical infrastructure plan or strategy for resilience (%) (UNISDR and CUDRR+R 2017)

2015) requiring transboundary collaboration between local governments. Furthermore, the complexity of ownership structures, and the potential gap between potential beneficiaries and those who bear costs of mitigation efforts and issues such as the integrity of and trust of information sources for potential public or private investments (Chang et al., 2014).

All these barriers indicate that achieving vertical and horizontal governance and working with different stakeholders in an effective manner are crucial for ensuring the resilience of critical infrastructure. The efficiency and capacity of local governance has an enormous impact on the risks communities face. Weak governance models would be incapable of managing the underlying risk drivers (Panda & Amaratunga, 2019), understanding the contextual needs, and using partnerships to increase capacities to address the adequacy and resilience of critical infrastructure in communities.

6 Conclusion

The availability of robust and resilient infrastructure influences the sustainable development cities and territories On the other hand, data shows that natural and manmade hazards and the impacts of climate change have a significant impact on existing infrastructure systems at both local and national levels. Such impacts are further aggravated by urbanization, emerging risks such as Covid-19 pandemic, and unsuitable investment decisions. Governments need to continuously monitor the adequacy of their existing infrastructure, upgrade and maintain them as necessary, and build new ones to provide for their increasing populations.

The importance of critical infrastructure, at local level makes it necessary to identify the role of local governments in addressing this issue, and to understand the barriers they face in undertaking it. This paper, thus examined, the role of local governments in addressing resilience of critical infrastructure and the barriers that they face in doing that.

It was necessary to position the importance of critical infrastructure within the context of the Sendai Framework for DRR 2015–2030, as it provides a roadmap for national governments with targets, principles, and priorities. The paper presented the importance of critical infrastructure, as understood by the Sendai Framework, to build resilient societies. However, due to the broad understanding of critical infrastructure across different sectors, the definition of critical infrastructure is varied among development actors and nations. On the other hand, a quick exploration of the subject indicated that despite the different understandings of critical infrastructure, there are common elements, such as infrastructure being physical or virtual assets that support social and economic wellbeing, safety and security, and ensure health and continuity of public services in communities. These common elements can facilitate the undertaking of measures addressing the resilience of interconnected and interdependent infrastructure systems. These measures need to equally strengthen the ability to resist, absorb, accommodate, adapt to, transform, and recover from the effects of any hazard in a timely and efficient manner, through engagement, adequate capacity, and risk informed governance.

At a local level, such measures can be guided by resilience assessment tools such as the Disaster Resilience Scorecard that was developed as part of the *Making Cities Resilient Campaign.* Indeed, local and sub-national governments that have joined the Campaign have at hand the tools that can guide them in developing the resilience of critical infrastructure in their cities and territories.

On the other hand, local governments are faced with several challenges that inhibit them from taking such resilience measures. Indeed, in a study among 214 cities that have joined the Campaign and used the Disaster Resilience Scorecard, it was observed that only 17% of the city's own and implement a critical infrastructure plan that highlights risks and continuity plans for essential infrastructure, services, and utilities. Research indicates that challenges that are faced by local governments in addressing resilient infrastructure largely rises from the interdependencies of infrastructure, ownership complexities, lack of incentives, and governance issues including the inadequate powers (authorities and capacities) of local governments.

As part of the challenge on interdependence of infrastructure, this paper has argued that understanding the system interdependence and cascading failures are important particularly in risk assessment, scenario building, and the design of necessary infrastructure systems that can be resilient in the face of stresses and shocks. This paper has also shown that the fragmented nature of ownership leads to the barrier of ensuring with compliance, and maintenance and upgrading of critical infrastructure. Indeed, a study undertaken by UNDRR and CUDRR+R among 151 cities have shown that only 31% of the local governments own or operate relevant assets in relation to critical infrastructure, while 39% of them are the sole responsible party in ensuring its resilience. The disparity in percentages indicate that some local governments are responsible to their constituencies in ensuring the continuity of services even though they do not own such utilities and infrastructure systems.

A third challenge this paper focused on is the lack of incentives for resilience measures. Particularly, taking in mind that ownership is fragmented, and a considerable part of the critical infrastructure is, directly or indirectly, controlled and operated by the private sector, it is necessary to provide them with incentives to improve their policies and practices to maintain, upgrade and take responsibilities in the provision of continuous service to their customers. In addition, due to the inadequate budgets of local and regional authorities, particularly at this time due to COVID-19 emergency, there needs to be strong partnerships between the public and private sectors where co-benefits of resilient infrastructure are further articulated.

And finally, a critical barrier to addressing critical infrastructure at the local level is related to governance issues. While local governments are at the forefront of disasters and they need to ensure risk reduction and resilience in their societies, they need an enabling institutional environment with adequate capacities (be it technical or financial) to address risk and resilience building. On the other hand, governance is a larger concept than just having necessary legislations and institutions in place. It involves strong leadership, coordination mechanisms with clear roles and responsibilities, as well as collaboration across all sectors, all actors, and all level (Gencer, 2019). The role of governance, then, particularly becomes important in addressing critical infrastructure at local level, as the operation of infrastructure due to the interdependence of infrastructure systems and the fragmented nature of ownership and operation. These characteristics of infrastructure, along with the variations in its contextual comprehension across different sectors and localities as was discussed in this paper, requires a multi-sectoral whole-of-society approach in addressing its resilience. Local governments then need to not only be provided with sufficient authorities and powers by national governments to address this issue, but also focus on participatory dialogue, decision-making, and action planning to accomplish it.

Considering the challenges highlighted in this article, the authors of this paper suggest:

1. to address holistic risk assessments, to investigate further the interdependencies and understand the interconnections among the infrastructure systems across the social, environmental, and physical spheres.
2. to address incentive challenges, to delve further into measurement of progress and performance of interconnected infrastructure and explore models that promote co-benefits; and
3. to address challenges rising from ownership and governance issues, identify partnership and good governance mechanisms that can support local governments and increase their capacities to address resilient infrastructure in cities and territories.

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Role of Disaster Risk Resilient Cities in Facilitating the Achievement of Sustainable Development

Lilian N. Smart, Richard Haigh, and Dilanthi Amaratunga

Abstract The rate of the urban population increase of most developing countries of the world in this twenty-first century is challenging, especially so because the natural and human-made disaster occurrences of the recent decades have demonstrated the vulnerability of most of these cities. Although it is widely accepted that urban centres are more exposed to natural hazards than rural areas, rapid urbanization may not be the only explanatory factor for city vulnerability, the lack of adequate disaster-resilient infrastructural facilities equally contributes to it. The increased population in these cities with little or no adequate infrastructure services and housing make people resort to living in slums and hazard-prone areas such as floodplains, steep slopes, low-lying lands, riverine and coastal areas. The sudden outburst of disasters in such cities without better-built disaster-resilient infrastructure can lead to destructions and losses which undermines the efforts geared towards the achievement of the Sustainable Development Goals (SDGs). In this context, this chapter aims at understanding the role of disaster-resilient cities in facilitating the achievement of SDGs in Nigerian urban settings through literature review and semi-structured interviews. Nigeria is one of the developing countries in the African continent that is experiencing rapid urbanization and regularly prone to natural hazards such as floods and droughts without the infrastructural facilities capable of making its cities resilient to these hazards. The city of Aba in Nigeria, the case study of this research, is one of such cities. The interviewees discussed the role of disaster risk resilient cities in relation to the 17 SDGs, demonstrating that the availability of disaster risk resilient infrastructure in Aba will help to reduce the impacts of disasters and facilitate the achievement of the SDGs such as poverty eradication, zero hunger and quality education. Based on this, they argue that without disaster risk resilient structures in the city under study, disaster-induced destructions and losses can hinder the achievement of sustainable development. Thus, the findings vividly highlight the role of disaster risk resilient cities in facilitating the achievement of the SDGs in cities, arguing that urban disaster destructions and losses are developmental setbacks. Therefore, the chapter recommends that to achieve the SDGs, the government, urban planners, and other

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organizations in these cities should strategically take action on creating disaster risks resilient cities.

Keywords Cities · Disaster · Disaster risks reduction · Resilient cities · Sustainable development

1 Introduction

One of the significant challenges that the world faces today is the ever-increasing disasters such as earthquake and floods, which leads to massive loss of lives and property. Floods alone can cause an incredible loss of lives, property, infrastructure, businesses, and an increased level of diseases (Olanrewaju et al., 2019). According to them, the occurrences of an earthquake in any city can destroy the entire city while flood can damage or wash away homes and infrastructure, resulting to loss of lives, property, jobs, public and private services. While it is acceptable that earthquake is destructive, saying that it can destroy an entire city is rather an unnecessary exaggeration. The analysis of the First Half (1H) of 2020 reveals that there was a minimum of 207 natural hazard events that occurred in the 1H of 2020, total economic losses were 72 billion US dollars, with insured losses of about 30 billion US dollars (Global Catastrophe Recap: First Half of 2020 Analysis, 2020). Also, the report shows that during this 1H, natural disasters claimed about 2200 lives with flooding being the deadliest natural threat. Indeed, the above has shown the alarming destructions and losses that result from natural and man-made disasters with flooding being more pronounced. These destructions can be more alarming when a disaster occurs in the rapidly urbanising cities without disaster risks resilient structures.

The unplanned rapid urbanization occurring in most low and middle-income countries further fuels disaster-induced losses as this urbanization occurs without development and the necessary urban infrastructural facilities. It is this kind of urbanization that characterizes most of the low and middle-income nations as people in the rural areas continues to embark in rural–urban migration (Amaratunga, 2018), notwithstanding the lack of development and these facilities. It is an aspect of migration triggered by the availability of better economic opportunities contrary to the lack of economic prospects in rural areas; and it increases the urban population, and give rise to inadequate housing and the high cost of accommodation in these cities (Amaratunga et al., 2018). The housing challenge propel the migrant to resort to living in informal settlements, and disaster danger zones (Mani et al., 2019), not minding the lack of the required disaster resilience structures in place.

Regarding Nigeria, it is revealed that natural hazards in the country constitute of droughts, floods, and epidemics, which claim lives, destroy property and displaces people forcibly (Okon, 2018). The record advanced that most droughts in Nigeria affects about 3,000,000 people, flood affects about 3,014,265 people, while the epidemic affects 80,000 people. Apart from floods and droughts listed herein, it is confirmed that Nigeria is equally prone to destructive storms and desertification

(Mashi et al., 2019). Other natural hazards in Nigeria include extreme weather condition, extreme temperature, landslides, dry mass movements, wildfires, volcanic eruption, and earthquakes (Okon, 2018). These are types of disasters that can occur with devastating consequences, especially when there is a lack of disaster risk resilient infrastructure in the cities involved (Ritchie and Roser, 2014). One of such consequences is that it can frustrate the efforts that city planners and authorities put together for the achievement of sustainable urban development (Wamsler, 2014). Making it easy to conclude that although cities are the hub of economic activities and the key determinant factors in achieving the 17 Sustainable Development Goals (SDGs), urban disasters can hinder this as it occurs with massive destructions and losses.

The 2030 SDGs agenda calls for strengthening the capacity of all countries, in particular developing countries, to reduce risk, increase resilience and adapt to climate change over the next 15 years in 5 areas of critical importance: People, Planet, Prosperity, Peace and Partnership. The consequences emanating from disasters can hamper the achievement of these goals, and this may be more endangering in developing countries like Nigeria than the developed countries. As the former suffer from diverse environmental challenges resulting from climate change and natural resource degradation, lacks disaster-resilient quality infrastructural facilities and effective early warning system (Mani et al., 2019). Disaster risk resilient infrastructural structures is herein enlisted as one of the essentials for cities to withstand and quickly recover from disasters (McDaniels et al., 2014). Unfortunately, most of the cities in Nigeria are vulnerable to disasters due to the lack of these structures,

A considerable literature has been written on the disaster occurrences in Nigeria. For instance, Okoli (2014) postulates that the occurrences of disaster in Nigeria threaten its national sustainability. That this results from government negligence of disaster management while pursuing their development plans and programs. It is argued that this neglect is evidenced in the poor management of health reforms in Nigeria, notwithstanding the significant number of lives that are threatened by disaster and the high level of injuries people sustains during its occurrences (Olanrewaju et al., 2019). Another study conducted confirms that the country faces other disaster-induced severe consequences like economic loss and threat to lives (Nwoko, 2013). That apart from the threat to life and property resulting from most of these disasters, its occurrence has continued to render thousands of people homeless through forced displacement (Nwoko, 2013). Considering these impacts, Wand et al. (2015) propose two important ways to reduce disaster risks. First, there is a need for disaster risks reduction education in Nigeria, teaching it in all stages. Second, that it is important to turn human knowledge into local action to reduce disaster risks in Nigeria (Wand et al., 2015). Based on this, they suggest the adoption of more positive and reliable procedures that can offer a sustainable control of the occurrences of flood in most of the cities in Nigeria to prevent disaster from escalating. Apparently, the above recommendations meant to reduce disaster risks in Nigeria seems to have not been implemented yet, as disaster occurrences and its consequences is still heightened in Nigeria.

The above are detailed enumerations that reveal the impacts of disaster in Nigeria, with recommendations to help reduce these impacts. However, literature exploring the role of disaster risk resilient cities in facilitating the achievement of sustainable development in Nigeria seems lacking, hence the importance of this study. This study is further necessitated by the fact that the New Urban Age Agenda highlights the connection between the New Urban Agenda, the 2030 Agenda for Sustainable Development, and the Goal 11 of the agenda—sustainable cities and communities, and affirms their commitment to strengthening the resilience of cities and human settlements. Also, it was confirmed that SDGs can be achieved through the reduction of the urban disaster risk (UNISDR, 2015). This has shown that building disaster-resilient city is a key determinant factor in achieving SDGs (Gupta et al., 2019). Because it can reduce the unnecessary disaster-induced losses and destructions as well as facilitate the achievement of sustainable development in these cities.

Accordingly, this research aims to explore the role of disaster-resilient cities in facilitating the achievement of sustainable development goals in Nigeria with the city of Aba as a touchstone. The paper starts by briefly reviewing the literature on the concept of the SDGs, followed by the conceptual understanding of the trends of urbanisation. After this, the conceptual meaning of disaster will follow, and the disaster-resilient cities will be discussed, then disaster in the context of Nigeria. This will be followed by the research methodology. The findings, summary of the findings and conclusion will then be discussed. The next section discusses sustainable development.

2 The Concept of Sustainable Development

The sustainable development goals agenda are the 17 goals mapped out by the United Nations for the transformation of the world. Sustainable development is "development that meets the needs of the present without compromising the ability of future generations to meet their own needs" (Verma, 2019). It means that development can only be said to be sustainable when it does not only meet the various needs of the present but also does not comprise the ability of the future generations to meet their own needs. It also means that in the achievement of development for the present, conscious efforts should be made to preserve and conserve the planet so that it may not be a struggle to meet the development need of the future. Arguably, achieving this type of development does not happen with haphazard planning; it requires strategic and dynamic plans as well as the collaborative efforts of all stakeholders and think tanks to achieve (United Nations, 2019). Accordingly, the SDGs goals which in 2015 were mapped out and accepted by all the Member states of the United Nations is an all-inclusive clarion call towards ending poverty, protecting the planet and ensuring that all people enjoy peace and prosperity by 2030 (UNDP, 2020). Though the 17 SDGs appears to be independent, they are integrated and interrelated such that an action in one area affects the outcomes of the others thereby, balancing sustainable development in its three facets of social, economic and environment (UNDP, 2020).

The point that the SDGs are integrated with the success of one of the goals affecting the success of the others (UNDP, 2020), can mean that the failure of one of these goals may result to the failure of the rest of the goals. For instance, this study is centred on disaster risk resilient cities, which is among the 17 SDGs, "make cities and human settlements inclusive, safe, resilient and sustainable" (SDGs 11). What this may imply is that if a country fails in creating a disaster risk resilient city, such country may equally struggle to achieve the rest of the SDGs. The reason is that the destructions and losses that follow most disasters pose as a developmental setback. UNISDR (2015) in this context affirms that disaster risk reduction cuts across the various phases and sectors of development with 25 targets which are related to disaster risk reduction in 10 of the 17 SDGs. This strongly establishes the role of disaster risk reduction as a fundamental development approach and the core aspects of the 2030 Agenda for Sustainable Development (UNISDR, 2015). With this, the fact that the 17 SDGs are inter-related is confirmed.

The achievement of these inter-related 17 goals amidst the recent unprecedented urbanisation occurring in Nigeria is of paramount importance especially so because a greater percentage of the people in Nigeria now resides in cities (United Nations, 2019). As a result of the increasing urban population growth in most cities in Nigeria like Aba, the lack of disaster-resilient structures in these cities can cause significant harm during disaster occurrences. At this point, it is essential to discuss the trends of urbanisation in the next section.

3 Understanding the Trends of Urbanization

The rapid rate at which urban population increases globally is alarming. The report from the United Nations shows that in 2018 about 55% of the population of the world already resides in urban areas, and by 2050, 68% of the population is projected to be urban (United Nations, 2019). The urban population growth in developing countries like Nigeria is also overwhelming. Nigeria is projected to add about 189 million urban dwellers between 2018 and 2050, almost doubling up the size of its existing urban population. Malalgoda and Amaratunga (2015) state that it is this increased urban population that leads to the concentration of diverse commercial and industrial activities in the cities, better education, employment opportunities and good healthcare facilities that supports increased life expectancies. While this explains what happens in most countries of the world, it is important to state that most urbanising countries like Nigeria still lack most of these infrastructure and social amenities in its urban centres yet continues to urbanise rapidly. Strikingly, those facilities that can help reduce disaster risks and enhance the achievement of sustainable development goals in their cities are also lacking.

This is mostly because Nigeria urbanises without development, a situation that results to challenges such as environmental degradation, overcrowding of these cities, increased number of people living in urban slums and informal settlements due to the lack of adequate and affordable accommodation. Such cities without the needed infrastructure in place exposes its population to acute shocks from disasters such as floods and earthquakes (Hernantes, 2019). Mani et al. (2019) state that the migration of people to cities and the settlement of these people in the unaccustomed atmosphere for economic reasons put their physical and social wellbeing at risk. While it is clear that people migrate to the cities, it can be argued, however, that the physical and social wellbeing of these migrants are not at risks mostly because they moved to the cities but because these cities are far from being disaster risks resilient. In other words, increased disaster risks in urban centres are not necessarily because of rapid urbanisation; factors such as lack of urban planning and lack of disaster-resilient infrastructure can provide additional explanations. Indeed creating disaster-resilient cities requires the strategic plans and efforts of all the urban stakeholders (Malalgoda & Amaratunga, 2015). Thus, it becomes crucial to discuss the concept of disasters.

4 The Conceptual Understanding of the Term Disaster

There is no singular definition of the term disaster as it appears to be a complex term with diversified definitions. It is argued that disaster is a catastrophic resulting in considerable loss of lives and destruction of property and causes other damages that are beyond the coping capacity of the community involved (Mani et al., 2019). It has been noted that the occurrence of most disasters causes significant interruption of the functioning of cities; generating human, material, economic or environmental losses which in most cases surpasses the ability of the affected community or society to cope using its own resources (Wedawatta et al., 2016). With this explanation, it becomes clear that disaster is catastrophic, and leads to massive destructions and loss of lives such that a particular country may not be able to handle by themselves but needs an external assistant. The report from the United Nations Disaster Risk Reductions shows that most urban areas are bedevilled with such disasters as earthquake, landslides, volcanic eruption, tsunami, cyclone, floods, drought, and fire (UNDRR, 2015). For instance, Indian Ocean Tsunami (2004), earthquakes in Italy (2009), floods in Pakistan (2010), Haiti (2010), Japan (2011), have caused large scale losses and damages (Siriwardena et al., 2013). Nigeria is not left out in this, the Malaysian flood of 2019, which left a lasting devasting mark in the lives of people caused significant losses and destructions too (The Daily Times Newspaper, 2019). This could be why the International Council for Local Environmental Initiatives state that the major successes or failures of the SDGs will depend upon the progress made on the urban goal (SDG 11) (ICLEI, 2015).Thus, the creation of disaster resilient structures in the cities is considered a better option for countries wanting to achieve the SDGs.

It is important because with the level of disaster-induced destructions and losses, it may be difficult for any country to achieve the sustainable development goals agenda of 2030. In fact, there is need for the development of effective disaster risk reduction strategies for communities at risk because of the increasing rate of devastating disaster events that are reported around the world recently (Wedawatta et al., 2016). Based on these facts, one can conclude that the occurrence of disasters is mostly not destructive because of the rapid urban population but because of the following:

1. Poorly constructed urban infrastructure in these cities.
2. The lack of effective urban planning with strategic land regulation to curtail the level at which people build and live in disaster-prone areas.
3. The lack of collaboration among city stakeholders in countries like Nigeria.

This lack of collaboration among stakeholders can make the achievement of disaster risk resilient cities difficult because the stakeholders need to gear their collective efforts to be able to create such cities (Malalgoda & Amaratunga, 2015). While gearing their collective effort is paramount to the building of disaster risk resilient city, it is also necessary for these stakeholders to develop a framework to fully understand the role of disaster risk resilience in these cities. An argument was put forward that although some cities have an already laid down frameworks for building city resilience; the frameworks that aimed specifically at operationalising the resilience-building process within most of these cities have remained undeveloped (Hernantes et al., 2019). Arguably, not having an operationalised framework for building city resilience is a problem that needs to be addressed urgently by city stakeholders to be able to achieve sustainable development. However, the coherent understanding of the role of disaster risk resilience in cities can hasten this. Accordingly, this paper explores the role of disaster risk resilient cities in facilitating the achievement of sustainable development in Nigeria. Now how can we make sense of the term disaster-resilient cities?

5 Disaster Risks Resilient Cities

Most cities in the world today, with reference to those in developing countries, are vulnerable to disaster risks, especially those without disaster risks resilience structures. Malalgoda and Amaratunga (2015), argue that any city that has no resilient physical systems, as well as resilient human communities, is exceptionally vulnerable to disasters. This line of argument has drawn our attention to the importance of the resilience of both the built environments, and the human communities. The term resilience has become prominent in matters of development and vulnerability reduction sectors. Siriwardena et al. (2013) confirm that the concept of resilience is now widely adopted across academic and policy debates as a way of reducing society's vulnerability to the threat of disasters. As such building cities that are resilient to disasters, urban centres that can withstand the shock of climate-related challenges like disasters is presently a rising concern among policymakers and international communities (Gamaralalage et al., 2020).

There are several definitions assigned to urban resilience. Urban resilience is the capacity of individuals, communities, institutions, businesses, and systems to survive, adapt, and flourish irrespective of the chronic stress and acute shocks they experience following a disaster (Spaans & Waterhout, 2017). They add that this resilience covers the capacity of a city to prevent disaster risks, to mitigate those risks, and to respond to minimise losses and destructions (Spaans & Waterhout, 2017). Urban resilience makes it possible for an urban system to precipitously return to desired functions in the face of a disaster (Meerow & Newell, 2019). It is also the ability of cities to resist, absorb, adapt to and recover from disaster-induced shocks and stresses (Hernantes et al. 2019).

Above are elaborate definitions of the term urban/city resilience, as they spell out the vital concepts of resilience, such as the ability of cities to withstand disasters and bounce back better. These are explanations that can apply to almost all cities. The above equally called our attention to the fact that in addition to the resilience of the physical structures, human resilience is a necessity. Importantly, the definitions of urban resilience presented above can be interpreted to mean that with the right disaster resilient structures, cities cannot completely collapse after a disaster. However, no one city is the same, and as a result, the meaning of disaster resilience or what constitutes disaster risks resilience structure in one city may not be the same as the others. During the interview, the interviewees were given an opportunity to define what disaster risks resilient city means in the context of Aba and here is their proposed definition:

"Disaster risk resilient cities are those cities that are consciously planned, designed with adequate and well-built infrastructural facilities aimed at reducing the vulnerability of the city—its infrastructure and residents during and after disasters (Interview, 2020)." The interviewees further state that this better-built infrastructure should include adequate and affordable housing, good roads, restructured and reconstructed urban slums, resettlement of people in disaster-prone areas with alternative livelihoods, well-built urban bridges etc. The above is apparently how the interviewees define disaster risks resilient cities and it all points to the fact that cities are said to be disaster resilient when the vulnerability of the residents is reduced to the barest minimum.

However, emphasise should be laid on the fact that there is a need to conduct a detailed disaster risks assessment for effectiveness and efficiency disaster risks reductions. Amaratunga et al. (2018) confirm that for disaster risks reduction measures to be effective, city planners must have a clear understanding of the risks that bedevils these cities. Risk assessments are, therefore, critical in understanding the risks and for making informed decisions on how best to prevent or mitigate the risks. Moreover, to make cities resilient to disasters, there are ten recommended essentials by the United Nations Office for Disaster Risks Reduction (UNDRR, 2019). Here are the lists of these essentials for reference purpose in this paper:

Essential One: Organise for disaster resilience.
Essential Two: Identify, understand, and use current future risks scenarios.
Essential Three: Strengthen Financial Capacity for Resilience.
Essential Four: Pursue Resilient Urban Development and Design.
Essential Five: Safeguard Natural Buffers to Enhance Ecosystems' Protective Functions.
Essential Six: Strengthen Institutional Capacity for Resilience.
Essential Seven: Understand and Strengthen Societal Capacity for Resilience.
Essential Eight: Increase Infrastructure Resilience.

Essential Nine: Ensure Effective Disaster Response.
Essential Ten: Expedite Recovery and Build Back Better.

Indeed, these are impactful essentials that can be adopted to make cities resilient to disasters. However, the type of city involved and the kind of disaster occurrences in such a city can necessitate the prioritising of one essential over the others in a country. Meaning that if a country has achieved essential eight—increased its infrastructure resilience already, such country may not need to do anything on that essential but will prioritise other essentials.

Following the information generated from the research participants during the research interviews in the city of Aba, Abia state Nigeria, it was discovered that this city is exceptionally vulnerable to disaster due to the lack of resilient infrastructural facilities, no resilient urban design, no strategic plans for effective early warning system and no adequate disaster response in place (Nwoko, 2013). These enumerated factors can necessitate the urban planning to prioritize most of the essentials like essential 8—infrastructural resilience, better and quality housing over the others to reduce disaster risks in Aba. Malalgoda and Amaratunga (2015) affirms that several disasters could be avoided with better housing facilities, infrastructure, and services. This explains why the urban planners in this kind of city need to make essential eight a priority over the others. With this perspective, it becomes necessary to argue that in most developing countries, the requirement of some essentials in its cities is more prominent than the others. That notwithstanding, achieving the entire ten essentials is paramount. In any case, the creation of disaster-resilient cities can facilitate the achievement of sustainable development in countries such as Nigeria.

The above has clearly documented the meaning of disaster-resilient cities and the importance of building disaster risk resilience cities. The report from the United Nations Office for Disaster Risk Reduction (UNISDR), which examines the links between disaster risk reduction and development in the context of 2030 Sustainable Development agenda and the Sendai Framework for Disaster Risk Reduction 2015–2030, reaffirms categorically the urgent need to reduce the risk of disasters in the cities (UNISDR, 2015). There is also a confirmation that the 2030 Sustainable Development Agenda including the Sendai Framework, the Sustainable Development Goals, the Addis Ababa Action Agenda, the Paris Agreement on climate change, and the New Urban Agenda recognise the important role cities play in development (Gencer, 2017). The implication may be that the lack of disaster risks resilience in cities can, in one way or the other hinder the achievement of sustainable development. The case is not different in Nigeria as disaster ravages its cities. Accordingly, disaster in the context of Nigeria will be discussed, in the next section, albeit in brief.

6 Disaster in the Context of Nigeria

It has already been demonstrated that to achieve sustainable development in any city; there is need to build a disaster risk resilient structure that will help to ensure the effective reduction and management of urban disaster (Malalgoda & Amaratunga, 2015). Urban disasters are disasters that take place in an urban setting or cities (Wamsler, 2014). Building urban disaster-resilience structure is needed in cities in Nigeria to make it capable of withstanding the shocks of disaster occurrences. Scholars have done considerable research on disaster occurrences in Nigeria (Nwoko, 2013; Okoli, 2014; Olorunfemi, 2008). The research conducted by Olorunfemi (2008), reveals that Nigeria is one of the disaster-prone countries of the world where the frequency and intensity of disasters have continued to increase with significant losses and destructions. The research shows that Nigeria experiences constant disasters like floods which occur annually in most of its cities with alarming consequences (Nwoko, 2013). A recent disaster that occurred in Aba in 2019 destroyed houses and property worth millions of Nigerian naira (The Daily Newspaper, 2019). One of the scholars notes that the several efforts of both the government and the residents of Aba to prevent or manage the constant occurrences of disasters in that area yielded insignificant results (Nwoko, 2013). While these efforts are acknowledged, it is also important to note that for those efforts not to work effectively; it may mean that they are not gearing their efforts toward the right strategies. The government need to explore various options and find out what works better with the city of Aba. They should consider creating a lasting and effective disaster risks resilience infrastructural facility in that city, especially so because the interviewees identify the lack of these facilities. This can help to curb the destructive impacts of disasters like the one that took place in a market in Aba called the Malaysian market following a flood disaster.

According to the report from the Daily Times Newspaper, the flood in Malaysian market in Aba destroyed goods and property worth millions of naira, flooded houses, shops, cars at the nearby mechanic village, including the major roads that lead to the central business areas (The Daily Times, 2019). This incident is one of the examples of the destructions caused by disaster events in Nigerian cities, and it is made worse by the lack of disaster risk resilience structures. To be able to achieve a disaster risk resilient city, the city stakeholders need to understand its role in facilitating the achievement of sustainable development. When this is done, it will enable them to put in a holistic urban planning approach to make these cities capable of withstanding the disaster shocks and bounce back better (Hernantes et al., 2019). The importance of urban planning in creating disaster risk resilient cities is pronounced (Malalgoda & Amaratunga, 2015). The reason is that an unplanned urban growth leads to numerous vulnerabilities in the cities such as physical, social and economic vulnerabilities. Therefore, to reduce the vulnerabilities of cities and increase its resilience, there is also a need for all urban institutions responsible for urban planning and development to undergo some level of reforms (Gupta et al., 2019). This will help them to re-strategize and work towards strengthening the resilience of the cities in Nigeria as disaster events have continued to be a threat to the country at large.

In re-strategizing, there is a need to adopt more positive and reliable procedures that can offer sustainable control of the occurrences of flood in most of the cities in Nigeria like Aba as advised by Nwoko (2013). Additionally, it is vital to turn human knowledge into action to reduce disaster risks as well as teach all stages of disaster risks reductions in schools (Wand et al., 2015). While the suggestions of Nwoko (2013) and Wand et al. (2015) is considerable, it was silent over the role of disaster risk resilient cities in all of these. However, the combination of their ideas with the creation of disaster risks resilience city will drastically reduce disasters and its consequences. Notably, this chapter focuses on the role of disaster risk resilient cities in facilitating the achievement of sustainable development in Nigeria. The next section details the research methodology adopted in achieving this.

7 Research Methodology

This research centres on exploring the role of disaster-resilient cities in facilitating the achievement of sustainable development goals in Nigeria, with the city of Aba as its case study. Case study research strategy has been selected as the most suitable strategy in this research as it helps the researcher to get an in-depth inquiry into the topic of study within its real-life setting (Yin, 2014). The research was conducted within a selected geographical urban location called Aba in Abia State. As the focus of the paper is on disaster-prone cities, the researcher selected the city of Aba because it is one of the cities in Nigeria bedeviled with constant disasters—floods worsened by the lack of adequate and better infrastructural facilities, making it highly vulnerable to floods. The occurrences of disasters in this city result in significant harm to the inhabitants of the city, their goods, houses, property and lives during these seasons. The researcher conducted a detailed literature review to understand state of the art, supported by 12 semi-structured interviews conducted among selected residents of Aba. Accordingly, several individuals, urban planners and academia/lecturers formed the research participants. This selection is based on the fact that the national governments, local government associations, international, regional and civil society organizations, donors, the private sector, academia, professional associations and the citizens are identified as city stakeholders. These individuals include those residents affected by disasters, directly and indirectly, several experts selected from the urban planners, and academics in the field of disaster management and disaster risks reductions. While three (3) individuals were selected because they were in one way or the other affected by disaster and will provide first-hand information of their experiences, four (4) urban planners and five (5) academia were selected based on their expert knowledge in the field of study. The interviews captured the knowledge of the interviewees on how they think disaster-resilient cities can help to facilitate the achievement of sustainable development. To understand how disaster-resilient cities can enhance the achievement of such goals as poverty eradication, zero hunger, good health, and education in Aba. Each of the face to face interviews lasted for about 60 min, duly recorded with a digital voice recorder, upon their permission. The interviews were conducted linking it to the 17 SDGs. Afterwards, the interviews were then transcribed manually using MS Word and analyzed and discussed. The next section will present the discussions of the results of the interviews on the roles of disaster-resilient cities in facilitating the achievement of sustainable development in the city of Aba, Nigeria. The next section will focus on the discussion of findings.

8 Findings: Role of Disaster Risks Resilient Cities in Facilitating the Achievement of Sustainable Development

The review above, discussed sustainable development as one of the core aspects of this research, other concepts reviewed include the trends of urbanization, the concept of disaster and disaster risks resilient cites, among others. It is important to note that the review and the interviews reveal diverse perspectives on the meaning of disaster risk resilient cities which is another core aspect of this research. From the reviews, the need for a disaster-resilient city and its importance in achieving the SDGs was fully demonstrated; revealing that the lack of it can increase disaster-induced consequences—destructions and losses. Having reviewed literature on disaster risk resilient cities as one of the critical factors that can facilitate the achievement of SDGs in most developing countries, it is important to analyze the data collected from the city of Aba. Using the SDGs goals as a framework, an opportunity was given to the interviewees to discuss the role of disaster risks resilient cities in facilitating the achievement of the 17 goals of the SDGs in Aba. At this point, the results from the interviewed will be discussed below.

8.1 Goal 1: End Poverty in All Its Forms Everywhere

The interviewees explained that Nigeria is among the countries struggling with poverty, that since disaster leads to wastages of human and material resources, it sets Nigeria back from its fight against poverty. They advanced that sudden disaster occurrences in Aba without the required disaster-resilient infrastructure will end up pushing the already impoverished masses and the poor economy into more abject poverty. According to one of the participants, disasters are setbacks to development and the eradication of poverty bedevilling Nigeria, that as a result, building disaster risk resilient city is vital to achieving SDGs 1. This, in effect, means that going for the measures that can help to eradicate poverty in a country rather than those that can escalate it should be of paramount importance to any country. In pursuing this, countries should consciously put in place disaster risks resilient infrastructure. As noted by UNISDR (2015), an urgent need is required to build and strengthen the resilience of poor communities to prevent potential disaster events from dragging more people into poverty. Thus, the role of the disaster risk resilient city in poverty reduction/eradication is highlighted.

8.2 Goal 2: No Hunger

It has been revealed that natural hazards can cause global food insecurity and hunger, especially if it compounds existing economic vulnerability of a city (UNISDR, 2015). This corresponds with the findings of this study as the interviewees stated that disaster occurrences in Aba are a major cause of food insecurity and hunger that ravages the people. Especially because farming and fishing is the predominant occupation of most people in Aba. Interviewee 6 said that during most of the disasters they experienced in this city, floods penetrate their farmlands, washed away their agricultural products, destroy agricultural assets and infrastructure. A situation they argue results in the destruction of peoples' source of livelihood and leads to a shortage of food in the city. These are apparent destructions that can consequently be setbacks to the achievement of the SDGs 2. On this note, it can be argued that the availability of disaster risks resilience in the city of Aba, will reduce the damages caused to agricultural productivity. It will also reduce the subsequent hunger that results from low agricultural productivity thereby facilitating the achievement of the SDGs 2. Indeed, this is one of the roles of a disaster risks resilience infrastructure.

8.3 Goal 3: Good Health and Wellbeing

Mentioning some of the names of his relatives who lost their lives during some of the disasters that occurred in Aba, one of the interviewees states that their death results from the lack of adequate medical attention. That also the lack of adequate disaster emergency services to handle the aftermath of health-related issues emanating from the disaster occurrences in that city contributed to their death. According to him, though there is a lack of adequate healthcare facilities in Aba, disaster destroyed the already deteriorated healthcare facilities. This is to the point that most people injured during the disaster lost their lives eventually because of the lack of timely and adequate medical attention. The interviewees suggest that the government should build adequate healthcare facilities in Aba and create disaster risks resilience infrastructure to help mitigate disaster-induced damages that can set back the achievement of sustainable development in the city of Aba. This demonstrates that damages to healthcare facilities caused by disasters do not only interrupt the healthcare systems; it also threatens the health and wellbeing of the people (UNISDRR, 2015). Thus, this situation requires urgent intervention in the provision of adequate healthcare facilities and the creation of an environment that is disaster resilient.

8.4 Goal 4: Quality Education

One of the consequences of the lack of disaster-resilient infrastructure in Aba was the identified destruction of the educational infrastructure following disaster occurrences in that area. According to one of the interviewees, some of the schools in Aba are built around disaster-prone areas and faces constant threat during the flooding period. The interviewee notes that during this period, the schools are flooded, infrastructure covered in flood, the route to the school closed for a prolonged period and children prevented from going to school under those circumstances. The interviewees raised the concern that situations like this can no doubt frustrate the efforts geared towards the achievement of the SDGs 4 in Aba. Their reason is that these disasters do not cause only damage to the school's infrastructure; it disrupts education and leads to loss of lives. Based on this, the interviewees suggest that the government should consider relocating those schools built in disaster-prone areas and equally work towards building disaster-resilient schools that will help to ensure that quality education is achieved in these schools without disruptions. Ensuring that there are no disruptions to education is important because it has been noted that education plays a crucial role in reducing vulnerability and in building community resilience to disaster risks (UNISDR, 2015). Therefore, it is acknowledged that education can help reduce disaster risks and that the government needs to relocate schools from disaster-prone areas. However, the creation of disaster-resilient structures does not necessitate the provision of quality education, contrary to the point raised by one of the interviewees above. This is because the provision of quality education requires investment in well-trained teachers and teaching equipment. Notwithstanding, most of these factors can in one way or the other facilitate the achievement of SDGs 4, while the provision of disaster-resilient infrastructure can reduce disaster destructions and losses that ravages the educational systems.

8.5 Goal 5: Gender Equality

Interviewees stress the fact that disaster threatens the lives of women and girls globally, thereby widening the gender inequality gap which may hinder the achievement of the SDGs 5. They state that girls and women are more exposed to dangers during disasters such as suffering higher rates of mortality and significant damage to their livelihoods. This they argue results from such factors as the lack of sustainable income for the women, and cultural prohibitions, prohibiting women from doing some things to help themselves in times of needs. The interviewees state that gender inequality is more pronounced in most cities in Nigeria than the others. In most of these situations, the man is seen as the head with the responsibility of fending for the family while the women are meant to remain at home with no source of income thereby becoming more vulnerable. The vulnerability of girls and women during disasters is traceable to gender inequalities connected with socio-economic and cultural situations (UNISDR, 2015), and limited resources. No wonder, the interviewees argue that gender inequality should be abolished. Those women should also be empowered to increase their resilience during and after disasters as that will facilitate the achievement of the SDGs 5. This is acceptable because gender inequality can heighten the vulnerability of women during disasters and limit the efforts geared towards the achievement of sustainable development.

8.6 Goal 6: Ensure Access to Clean Water and Sanitation for All

The interviewees identified that though there is lack of drinking water in the city of Aba, as the government neglected that aspect of the necessities of life, disasters have continued to undermine the efforts of private individuals and other philanthropists who work hard to provide access to drinkable water for themselves and sanitation for as many as possible. They add that the occurrence of disaster in the city of Aba with reference to the water-related disasters such as floods, droughts and storm surges destroys all the facilities for the provision of drinkable water. This is challenging because to address the disaster-induced vulnerability and to strengthen the resilience of communities to water-related hazards; sustainable water management is vital (UNISDR, 2015). Accordingly, it is good to draw attention on the fact that the achievement of the SDGs 6, also depends on the provision of sustainable water management and strengthening of the resilience of people and communities to flood-related challenges.

8.7 Goal 7: Ensure Access to Affordable, Reliable, Sustainable and Modern Energy for All

Although Aba has been struggling with intermittent energy supply, most of the interviews state that the destructive act of disasters affect the energy infrastructure in the city of Aba and significantly affect the energy supply. They further state that achieving SDGs 7 under these prevailing circumstances may not be possible. According to one of the participants, investments in energy infrastructure worth significant amount of money are lost to disasters yearly, resulting in significant social and economic disruptions. He emphasised that if there is accurate data on the loss of energy infrastructure in Aba following the occurrence of disasters, it will be a shock as to how much set back the city experiences in its pursuit to achieve sustainable development. As a result, the importance of building resilient infrastructure, promote the resilience of the new and existing infrastructural facilities to ensure that they are safe, effective and operational during and after disasters as specified by UNISDR (2015), is critical to the achievement of SDGs 7.

8.8 Goal 8: Decent Work and Economic Growth

Recalling the flood-induced destruction of shops, businesses, assets and infrastructure that took place in 2019 in the Malaysian market, Abia State, Aba (The Dialy Newspaper, 2019), an interviewee argue that it is preventable losses. According to him, the infrastructural facilities with which the market is built may not be disaster-resilient yet exposed to disasters. His major line of argument is that it seems there were no prior risks assessment of the area by the urban planners before creating a market of that nature. Here, the importance of risk assessment, as argued by Amaratunga et al. (2018), is emphasized. To one of the interviewees, that kind of disaster is a significant setback to the community and the nation at large. This is in line with the postulation that disaster constitutes a significant threat to the development and economic stability of both developed and developing countries (UNISDR, 2015). Drawing from the above, it can be argued that the occurrence of disaster is destructive and even more destructive when it occurs in a city without disaster resilient infrastructure. When this is done, it can destroy all that has been put in place to achieve sustainable development. As a result, it is crucial to think of disaster-resilient infrastructure when thinking development.

8.9 Goal 9: Industry, Innovation and Infrastructure

An interviewee opined that Aba lacks adequate industry and infrastructure, yet disaster continues to destroy the little that is available, and the governing authorities seem silent over it. According to them, most of the investments and industries in Aba are owned by private individuals. That despite the overwhelming investments of people in these sectors and the revenue it generates to the government, the environment lacks disaster-resilient infrastructure; thereby making the investments and the investors vulnerable to disasters. They argue that when this happens, the level of destructions that will take place can undermine the efforts of the government to achieve sustainable development. Indeed, the occurrence of disaster in this investment area will no doubt disrupt essential services and jeopardise the sustainability of the nation at large. When this happens, it can hinder the timely achievement of the SDGs in Aba.

8.10 Goal 10: Reduce Inequality Within and Among Countries

Interviewee 7 explained that there is a widening gap between the rich and the poor, men and women in the city of Aba. Although she was clear about this rising inequality in Aba, she was not clear on whether disaster occurrences escalate this further or not. However, interviewee 5 argue that disaster can lead to increased inequality in Aba, and if unchecked, it can affect the achievement of the SDGs. Drawing from his experiences of the past disaster events in Aba, he explained that the source of the livelihoods of some people was destroyed and others lost their jobs, dragging them into more abject poverty. This line of argument confirms what happened during the Hurricane Katrina in 2005, a disaster that reveals the inequality between men and women, with the income of men being well above that of women (UNISDR, 2015). Why and how disaster can lead to an increase in the income of one and a decrease in the income of another is a question that needs an answer. However, it is not within the purview of this research to answer this question. The important fact here is that there exists some level of inequality in Aba and there is need to abolish this financial, social, economic, and cultural inequalities. This is to reduce the vulnerability of those whose income and livelihoods are usually affected, increase their resilience, and enhance the achievement of the SDGs. Accordingly, the issue on the human aspect of resilience—resilient human communities raised in the explanation of the term resilience by Malalgoda and Amaratunga (2015) and the interviewees has re-emerged here to show the importance of that aspect of resilience.

8.11 Goal 11: Sustainable Cities and Communities

Considering the report of the United Nations suggesting that more than half of the population of the world resides in the cities, interviewees were asked to explain ways to achieve the SDGs 11 in the face of the alarming urbanisation in Aba that is both rapid, unplanned with bedevilling poverty. The interviewees addressing this question started by pointing out that the city of Aba is far from achieving SDGs 11. According to them, sustainable cities and communities are those with adequate infrastructural facilities that are resilient to disasters such as good roads, drinkable water, electricity, better livelihoods, good schools, good communication systems, job opportunities, among others. The interviewees noted that the government seems silent over these essential services while continuing their campaigns on the achievement of the SDGs agenda by 2030. Interviewee 8, urban planner state that efforts are being made to focus on making cities and human settlements inclusive, safe, resilient, and sustainable in Aba, only that the result seems slow but steady. According to him, these efforts include awarding contracts to trusted people to build more houses and provide other infrastructure to make the city sustainable. However, one of the interviewees raised a contrary opinion stating that the only efforts he can see that the government and urban planners are making is investing more resources on the SDGs campaigns. As such he argues that the city of Aba requires strategic action to make it sustainable rather than mere knowledge and campaigns. This last line of argument confirms the importance of turning human knowledge into action to reduce disaster risks in Nigeria (Wand et al., 2015). Indeed, the achievement of the SDGs 11 in the city of Aba is important and from all the arguments, one can deduce that there is little or no evidence that the city of Aba is ready for sustainability and resilience yet. It is highly recommended that action should be taken in that direction because achieving SDGS 11 is important in achieving the rest of the SDGs. Moreover, the report from the United Nations made it clear that building inclusive, resilient, competitive, and sustainable cities and communities is essential for achieving the SDGs by 2030 (United Nations, 2019).

8.12 Goal 12: Responsible Consumption and Production

Referring to an area in Aba where people dump their wastes indiscriminately, an interviewee expressed concern that this can cause flooding that could destroy some vital structures. According to him, after one of the flooding events that took place in that city, the disaster wastes were dumped there, and the government visited that site for inspection, gave rays of hope on proper waste management, yet no remedy in view till date. Another interviewee opined that creating proper waste management in that city will help to reduce disaster risks and facilitate the achievement of the SDGs. Although it is essential to create proper waste management, especially because it has been noted that its absence can trigger an increase in disaster risk (UNISDR, 2015), it is arguable that it does not mean that proper waste management is central to the achievement of the SDGs. This is because there are other more pressing factors that need to be addressed when working towards achieving sustainable development, and one of such is the building of better disaster-resilient infrastructure in the city of Aba. With this, it can be said that while proper waste management can facilitate the achievement of the SDGs, better built resilient infrastructural facilities will be more helpful because it will reduce disaster risks.

8.13 Goal 13: Climate Action

The interviewees suggest that there is need to take urgent action to combat climate change and its impacts in Aba if the government aims at reducing disaster risks because according to them, climate change escalates disasters. One of the interviews recounts that Aba has been experiencing diverse climate change such as a change in temperature, sea-level rise, droughts, and heavy downpour of rains leading to increased disaster risks in different areas of the city. Based on this, they advised that the government should take urgent action to ensure that climate change does not impede its development efforts. It is agreeable that government should take urgent action to achieve SDGs 13 so as not to jeopardise the chances of achieving the rest of the goals because according to (UNISDR, 2015), "climate change "magnifies disaster risk and increases the cost of disasters."

8.14 Goal 14: Life Below Water

While interviewee 3 stated that both the government and the urban planners in the city of Aba are doing "absolutely nothing" (in his own words) to conserve the use of the oceans, seas and marine resources in this city, interviewee 4 had a contrary opinion. According to Interviewee 4, most fishermen are still thriving in their profession in Aba because of the work that the government has put in towards the conservation and sustainability of the riverine areas of the city. Interviewee 4 advanced that the only setback to this governmental effort is disasters. To this, interviewee 3 argued that if the government is doing well as interviewee 4 stated, then they should have known the importance of creating resilient facilities to reduce the destructive outcomes of disasters in that area. As such, some of the interviewees concluded that the massive effect of disaster in this area is as a result of governmental negligence which is primarily because most selfish leaders feel that they do not benefit from that source directly. Hence, they become silent over the importance of disaster risks resilience facilities in that area. The inference that can be deconstructed from the above is that the government is making some efforts in conserving and preserving the oceans and seas and as such governmental negligence may not be the best explanation. One can argue that misplacement of priority and the choice of cheap and low-quality infrastructure over better and high-quality infrastructure by the government for selfish and political reasons can offer a better explanation, With this, it becomes important for the government and urban planners to go for high quality and better-built disaster risks resilient infrastructure to facilitate the achievement of the SDGs 14.

8.15 Goal 15: Life on Land

One of the interviewees pointed out that the degradation of the ecosystem of any country/city has negative impacts on the resilience of their city and increases the vulnerability of its inhabitants. According to her, one of the challenges in Aba is environmental degradation arising from desertification, agricultural activities, the conversion of land because of urban growth and expansion and building in the disaster-prone areas. Also, the extractive work of the extractive industries and pollution constitute a significant threat to the ecosystem. As a result, they suggest that government and the urban planners need to take urgent action to protect and restore the already degraded ecosystems so that its adverse effect, in the long run, will not negate the work put toward the achievement of SDGs. This is important because following the annual global estimates of losses to ecosystem services which is about US $190 billion (UNISDR, 2015), the importance of protecting and sustainably using ecosystems while working towards the achievement of sustainable development cannot be over-emphasized. Also, it is vital to add that in working towards the protection of the ecosystem, the government should equally maintain focus on better-built disaster resilient infrastructure in the city under study.

8.16 Goal 16: Peace, Justice, and Strong Institutions

Interviewee 11 narrated that conflicts both armed and violent can hinder the economic prosperity of any country because of its destructive impacts. According to him, for a country to prosper economically and otherwise, there is a need for a peaceful environment, an environment where there is prevalent peace and justice. Interviewee 1 affirms that conflict-affected cities do suffer from the lack of the ability to respond to disaster risks because attention may be diverted from responding to disasters to resolving the conflicts as both can generate massive destructions and losses. With this, they argue that for government to see progress in their efforts towards the achievement of sustainable development, there is need to ensure that the city of Aba remain peaceful, because a combination of disasters and conflict in the same city may erode it off the goal of achieving sustainable development. With this, one can argue that since conflicts can results to the destruction of infrastructural facilities just as disaster does, it can equally mean that disaster and conflicts are commonly re-enforcing (UNISDR, 2015) and measures to ensure that they do not occur should be a priority to enable the achievement of the SDGs.

8.17 Goal 17: Global Partnership

The interviewees believe that global partnership is a near impossible thing with the recent prevalent disaster occurrences. Referring to the pandemic that the world is battling with today, they argue that no country would want to partner with any country where the coronavirus is at its climax. They also said that there are countries who may not want to collaborate with other countries for personal reasons. While this may be true to an extent, it is somewhat too ambiguous to say that global partnership is a near-impossible thing especially with the high level of technological innovations that the world is enjoying in this twenty-first century. It can also be said that the world, especially the UN member nations, understands the importance of the success of the 2030 Agenda of the SDGs and the role of global partnership in achieving it, and may not want anything to put it on hold. They also understand that for the effective implementation of the goals, there needs to be collaborative participation of all stakeholders such as government organizations, the NGOs, civil society and the private sector (UNISDR, 2015). With this, the need for global partnership in the achievement of the SDGs is pronounced.

The above is the detailed analysis of the data generated from the interviews conducted. The next section will be a brief discussion of the results before proceeding to the conclusion of the chapter.

9 Discussion of Findings

Above section highlights the importance of building disaster risks resilient city and its role in facilitating the achievement of the 2030 sustainable development goals agenda. The discussions demonstrate the importance of creating disaster risk resilient infrastructure in cities to reduce the impacts of disasters—destructions and losses to facilitate the achievement of the SDGs in Aba. The empirical evidence has shown that the city of Aba is bedeviled with several developmental setbacks resulting mostly from disasters and may struggle to achieve the SDGs agenda by 2030. It was also clear that the city is urbanizing rapidly, and it is the unplanned nature of this urbanization that exposes the residents to disaster vulnerabilities. A situation that is made worse by the lack of disaster risks resilient structures. One of the arguments raised in the review is that the lack of disaster-resilient cities gives rise to severe destructions and losses during and after disasters, thereby impeding the efforts to achieve the SDGs. These discussions were evident in both the literature and the empirical data, with the empirical revealing the detailed explanation of how this applies to the city of Aba. Some of the line of argument put forward by the various research participants in Aba corresponds with the fact raised in the literature. For instance, there is a consensus between the literature and empirical study that though the 17 SDGs appears to be independent, they are integrated and interrelated.

An integration and interrelationship that denotes that an action in one goal affects the others (UNDP, 2020). In the case of the role of the disaster risks resilience cities in Aba, the interviewees show that the failure to create such cities in Aba can significantly affect the efforts put together towards the achievement of sustainable development goals. Especially so because the International Council for Local Environmental Initiatives (ICLEI), states that the achievement of sustainable and resilient cities which is SDGs Goal 11, is a right step to the right direction towards the achievement of SDGs (ICLEI, 2015). Accordingly, in the pursuit of sustainable development in Aba and every other city in Nigeria, the creation of cities that are sustainable and resilient to disaster is both critical and inevitable. However, it is worthy of note that the availability of disaster risks resilient infrastructural facilities in cities like Aba, does not prevent disaster occurrences rather it can only reduce the risks—destructions and losses associated with disasters. The next section is the conclusion.

10 Conclusion/Recommendation

This paper reveals the importance of building disaster risk resilient cities and show its role in the achievement of the SDGs in Nigeria, precisely Aba, in Abia State. It underlines that reducing disaster risk by building human and infrastructural resilience in these cities is paramount to achieving the 2030 Agenda for sustainable development. From the literature reviews and the interviews conducted, it is evident that increasing disaster destructions and losses can affect the achievement of the SDGs. The interviewees noted that the losses associated with disasters will continue to destabilize the efforts to reduce poverty, achieve zero hunger, good health, education, gender equality, and the rest of the goals. While this is true, it important to note that there appears to be difference in the extent to which the lack of disaster risks resilient infrastructure can affect the achievement of each of the SDGs. Meaning that some SDGs can be affected more significantly by the lack of disaster resilient infrastructure than the others and this is revealed in the data. By exploring the role of the disaster risks resilient city through the lens of these 17 SDGs, the need for the government, urban planners, urban development agencies and other city stakeholders to create disaster risk resilient cities has been demonstrated.

The findings also suggest that failure to build disaster risk resilient cities in Aba will significantly hinder the achievement of the 2030 SDGs. Accordingly, unlike the recommendation of (Okon, 2018) that the Nigerian government should embark on reducing urbanization growth by reducing high rural–urban migration, this chapter suggest that the government and the urban leaders should focus on creating disaster risk resilient cities if they are aiming at achieving the 2030 SDGs agenda. Based on the result of this research, it is highly recommended that the urban planners in the city of Aba and the governing authorities alongside other stakeholders should hastily take action towards creating a disaster risks resilience city to facilitate the achievement of the sustainable development goals agenda by 2030.

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Disaster Risk Reduction

The Impact of PDO on South–West Monsoon Rainfall Over Sri Lanka and Monsoon-ENSO Relation

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Abstract The sources of variation in rainfall over the Sri Lanka during past few decades are puzzling and much attention has paid to decadal climate predictions because of the recognition that there is a necessity for long-term decisions to adapt to the impacts of climate change. However, the impact of Pacific Decadal Oscillations (PDO) on the south west monsoon (SWM) variability has not been satisfactorily discussed so far and no study has been explaining the detailed relation between PDO and south west monsoon mechanism. In this study, we investigated the fluctuations of southwest monsoon rainfall over Sri Lanka in relation to PDO observed in the sea surface temperature (SST) of the North Pacific Ocean. Rainfall of 21 meteorological stations in Sri Lanka for a period of 50 years were included and analyzed. During the period studied, there were three (03) cold phases, two (02) warm phases of PDO, ten (10) El-Nino events and sixteen (16) La-Nina events. Post maps were constructed for cold and warm phases of PDO in El-Nino and La-Nina events separately, using the monthly rainfall composites during the south west monsoon period. In the warm phase of the PDO, dry condition and in the cold phase of the PDO, wet condition is observed to develop over Sri Lanka respectively. Furthermore, during the warm phase of the PDO, the influence of El-Nino (La-Nina) on the south-west monsoon rainfall is increased (counteracted). These associations indicate that the PDO extends its effect from the North Pacific Ocean to the tropical Pacific Ocean and changes the relation between the El-Nino Southern Oscillations (ENSO) and the south-west monsoon rainfall.

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1 Introduction

There is a need for long-term predictions to address the impact of climate change and therefore recently much more attentions were paid for the decadal climate prediction. Natural law-frequency variations due to changes in regular powers that drive the globe and human environmental impact may be some of the reasons for these changes (Goddard et al., 2012; Liu, 2012; Meehl et al., 2009).

Large scale natural long-term oscillations which influences major interannual variations which are known as "teleconnections". (El Nino-Southern oscillations (ENSO), Atlantic Multidecadal Oscillations (AMO), Pacific decadal Oscillations (PDO), the Pacific-North American pattern (PNA) and the Western Pacific pattern (WP) are some of the examples).

The prominent decadal variations are observed mainly in the midlatitude oceans. PDO and AMO are clearly demonstrate decadal variations in the sea surface temperature (SST) in the North Pacific and North Atlantic oceans respectively (Goddard et al., 2012). The PDO exerts its influence on ecosystems (Mantua et al., 1997) and other regional climates (Minobe & Nakanowatari, 2002; Power et al., 1999) with a period of 20–30 years (Mantua & Hare, 2002) which would change and modifies the variation of the Tropical Pacific Ocean (Ouyang et al., 2014; Watanabe & Yamazaki, 2014).

The interannual variation of the South Asian monsoon rainfall mainly depends on the tropical Pacific Ocean basin (Krishnamurthy & Kirtman, 2009; Rasmusson & Carpenter, 1983) through Walker circulation which is subjected to alterations due to EL Nino-Southern Oscillations (ENSO) (Sumathipala & Punyadeva, 1998; Hapuarachchiand & Jayawardena, 2015; Premalal, 2013). Further earlier studies (Deser et al., 2004; Vimont, 2005) indicate that one of the possible routes for the decadal variation in the North Pacific Ocean to influence the monsoon is through the equatorial Pacific Ocean. Therefore, it is interest to examine the possible influence of the North Pacific variations on equatorial Pacific and whether it would change the monsoon-ENSO relationship.

The rainfall characteristics in Sri Lanka, an island near the southern tip of India, have similar rainfall characteristics in southern India during the active phase of the southwest summer monsoon (Suppiah, 1997). Raghavan (1973) and Sumathipala and De Silva (1981) identified during the break phase this pattern is reversed due to meridional circulation pattern. Characteristics of the circulation pattern during the south west monsoon season, are Monsoon trough, Cross equatorial flow and Law level westerly jet in the lower troposphere and Tropical easterly jet in the upper troposphere (Chap. 5 of IPCC AR4 model simulations). Influences of extremes of the ENSO phenomenon on the rainfall of Sri Lanka has been studied and found that the rainfall pattern during El-Nino and La-Nina are either above normal or below normal.

It was below normal in Southwest monsoon period (May–September) and above normal in October–November during El-Nino and it is opposite during the La-Nina phenomena (Suppiah, 1997; Sumathipala, 1999; Premalal, 2013; Hapuarachchi & Jayawardana, 2015). However, whether the PDO influences the South west monsoon rainfall variability has not been successfully explained so far.

The main purpose of the present paper is an examination of possible influence of the North Pacific SST and provide detailed space–time structure of the relation between southwest monsoon rainfall and PDO. Further, the influence of PDO on southwest monsoon rainfall-ENSO relation also examined.

2 Definition of Pacific Decadal Oscillation

The Pacific Decadal Oscillation (PDO) is defined by the leading pattern of Empirical Orthogonal Functions (EOF) of sea surface temperature (SST) anomalies in the North Pacific basin (typically, poleward of 20° N). The SST anomalies are obtained by removing both the climatological annual cycle and the global-mean SST anomaly from the data at each grid point. Positive values of the PDO index correspond with negative SST anomalies in central and western North Pacific (extending eastwards from Japan), and positive SST anomalies in the eastern North Pacific (along the west coast of North America) (Mantua & Hare, 2002; Mantua et al., 1997; Meehl et al., 2009; Minobe & Nakanowatari, 2002). The positive phase of the PDO is also associated with positive SST anomalies across the central and eastern tropical Pacific.

According to Fig. 1 the first 16 years of the data set 1961–1976 belongs to the cool regime. The next 21 years, the period during the years 1977–1997 belongs to the warm regime. Accordingly, the next 5 years period 1998–2002 belongs to cool regime, the next 05 years period 2003–2007 belongs to the warm regime and the final 3 years period belongs to the cool regime again.

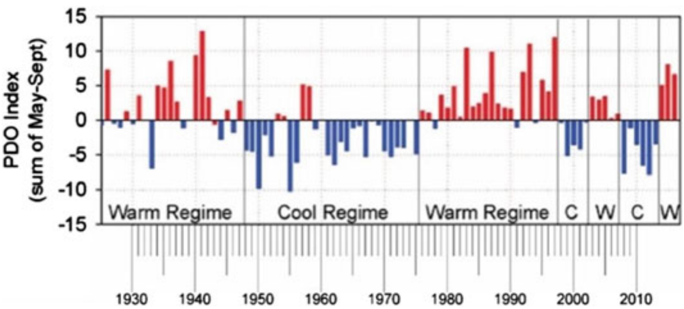


Fig. 1 Time series of shifts in sign of the Pacific Decadal Oscillation (PDO), 1925 to present. Values are summed over the months of May through September with modified time axis. Red bars indicate positive (warm) years; blue bars negative (cool) years

3 Data and Methodology

Fifty years (1961–2010) monthly rainfall data of 21 stations is used for this study. The rainfall stations were selected such that they were distribute evenly throughout the island. The vector winds at two vertical levels (500 and 850 hpa) were obtained from the National Centers for Environmental Prediction-National Centers for Atmospheric Research (NCEP–NCAR) reanalysis dataset for the period 1960–2010.

Thirty years monthly average rainfall for the period 1961–1990 and monthly rainfall average during the five months of the south west monsoon period (May–September) in the three cool and two warm regimes of the Pacific Decadal Oscillations within the years 1961–2010 were calculated separately for each rainfall station. Monthly rainfall anomaly was calculated for each month as the difference between the monthly average rainfall and the thirty years monthly average rainfall.

For each rainfall station the monthly rainfall composite was calculated as the ratio between the monthly rainfall anomaly and the thirty years monthly average rainfall of that month. For the whole southwest monsoon period rainfall anomaly composite was calculate as the sum of the five months monthly rainfall composites.

El-Nino and La-Nina years were categorized using Ocean Nino Index (ONI) (Huang et al., 2017) based on three month running mean of Sea Surface Temperature anomalsies in the Nino-3-4 region (5° N–5° S, 120°–170°) (Table 1).

Based on ONI, *National Oceanic and Atmospheric Administration* (*NOAA*) defines El-Nino as positive ONI greater than or equal to 0.5 °C and La-Nina as negative ONI less than or equal to −0.5 °C. An El Nino episode is classified when these conditions are satisfied for a period of at least five consecutive months (Climate Prediction Centre). Accordingly El-Nino years, the following year of the El-Nino, La-Nina years and the following year of the La-Nina were categorized for both cool and warm regimes of the PDO. The year is classified when these conditions are satisfied for a period of at least three months out of five months of the monsoon regime. For each cool and warm regime of the PDO, two rainfall anomaly composites were calculated as the sum of the rainfall anomaly composites of the respective El-Nino years (El (0)) and La-Nina years (La (0)) for each rainfall station.

If the percentage of this calculated value is less than −10% the station is considered as dry, if it is in between −10% and 10% the station is considered as neutral and if it is greater than 10% the station is considered as wet. The dry rainfall stations were marked by "Blue circles", neutral rainfall stations were marked by "Gary crosses" and wet stations were marked by "Red triangles".

These percentage values were used to plot the Post map using the software Surfer and the maps are shown below (Table 2).

Table 1 Selected stations with their latitudes and longitude

Station	Lon	Lat
Colombo	79.86	6.9
Ratnapura	80.4	6.68
Kurunegala	80.37	7.46
Kandy	80.63	7.33
NuwaraEliya	80.76	6.96
Badulla	81.05	6.98
Batticaloa	81.7	7.71
Ambalantota	81.02	6.12
Anuradhapura	80.38	8.35
Hambantota	81.13	6.12
Ratmalane	79.88	6.81
MahaIlluppallama	80.46	8.12
Katunayake	79.88	7.17
Ampara	81.66	7.28
Bataata	80.91	6.1
Welimada	80.9	6.9
Angamedilla	80.91	7.85
Galle	80.22	6.03
Kaluthara	80.03	6.58
Kurunduoya	80.83	7.07
Vauniya	80.5	8.75

Table 2 Selected El-Nino years during cool and warm regimes of the PDO

Cool		Warm	
El-Nino	La-Nina	El-Nino	La-Nina
El (0)	La (0)	El (0)	La (0)
1963	1964	1982	1978
1972	1970	1987	1984
2002	1971	1991	1985
2009	1973	1994	1988
	1974	1997	1989
	1975	2004	2007
	1998		
	1999		
	2000		
	2010		

4 Results and Discussion

4.1 *Impact of PDO on La-Nina Signal During Southwest Monsoon Season*

Monsoon trough, law level westerly jet and equatorial easterly jet are visible in Fig. 2a, c. But anomalous westerly wind flow appears at 850 hpa layer in Cool, La-Nina episode during SWM season towards northern part of Sri Lanka and may expect above normal rainfall throughout the Island except southern part.

Anomalous cyclonic circulation can be visible at the central of Bay of Bengal at 850 hpa layer may responsible for above normal rainfall over north east part of Sri Lanka during Cool, La-Nina SWM episode. In the anomaly map in Fig. 2b, d, it can be identified southeast-northwest oriented anomalous trough in 500 and 850 hpa layers over the north-east part of Sri Lanka and it tends to bring rainy wet weather to east and southeast regions of the Island.

In Fig. 2c equatorial easterly jet flow is visible. Anomalous southwest-east flow appears at 500 hpa layer in Cool, La-Nina SWM season which may be favorable for above normal southwest monsoon rains. Extended through associated with the anomalous circulation appeared to the north of Sri Lanka is favorable for enhancing rain over Sri Lanka.

Cross-equitorial low level westerly jet and Monsoon trough is clearly visible at 850 hpa in Fig. 3a. Anomalous west to east wind flow appears over Sri Lanka in Fig. 3d and anomalous cyclonic circulation visible in the north Bay of Bengol at 850 hpa level is favorable in enhance SWM rains with high intensity for the northern part of the country.

In Fig. 3c at 250 hpa pressure level tropical easterly jet is clearly visible and which is favorable condition for SWM rains over Sri Lanka. Anomalous cyclonic circulation appeared towards the eastern part of India enhanced the rainfall over Sri Lankan region. Figure 4b shows that approximately 85% of the selected stations receives enhanced rainfall in Cool, La-Nina episode.

During the Warm, La-Nina episode, the prevailing circulation conditions in the region at different pressure levels are favorable for SWM rainfall. Anomalous cyclonic circulations visible at the central Bay of Bengal in the lower atmosphere enhanced the SWM rains received, developing extended troughs over and closer to the Sri Lankan region. Anomalous easterly jet flow can be visible with two cyclonic circulations at 500 hpa level closer to the eastern coast of Sri Lanka and in the western Indian Ocean is also favorable situation to occur more rainfall. In the upper atmosphere anomalous cyclonic circulation is visible at the eastern edge of Bay of Bengal and produce extended easterly trough along the Nothern longitude 15° which can be favorable of weaken tropical easterly jet stream.

Figure 4b shows that approximately 67% of the selected stations receives enhanced rainfall in Warm, La-Nina episode

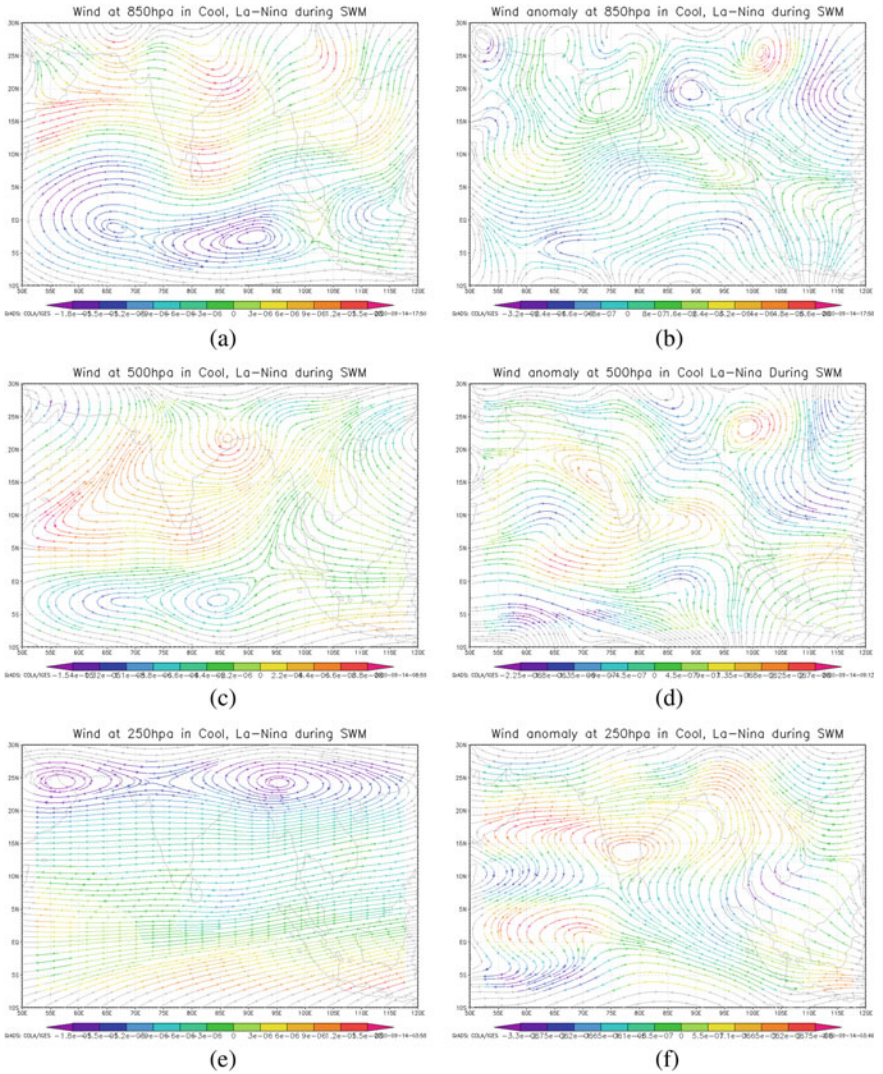


Fig. 2 **a** Wind at 850 hpa, **b** wind anomaly at 850 hpa, **c** wind at 500 hpa, **d** wind anomaly at 500 hpa, **e** wind at 250 hpa and **f** wind anomaly at 250 hpa in Cool, La-Nina during SWM period

It can be seen that minor changes occur in the SWM rainfall received to the selected stations located in the central, western and south eastern regions of the country in La-Nina episode during cool and warm PDO regimes. For both PDO regimes majority of the stations selected for the study receives enhanced rainfall during La-Nina episode.

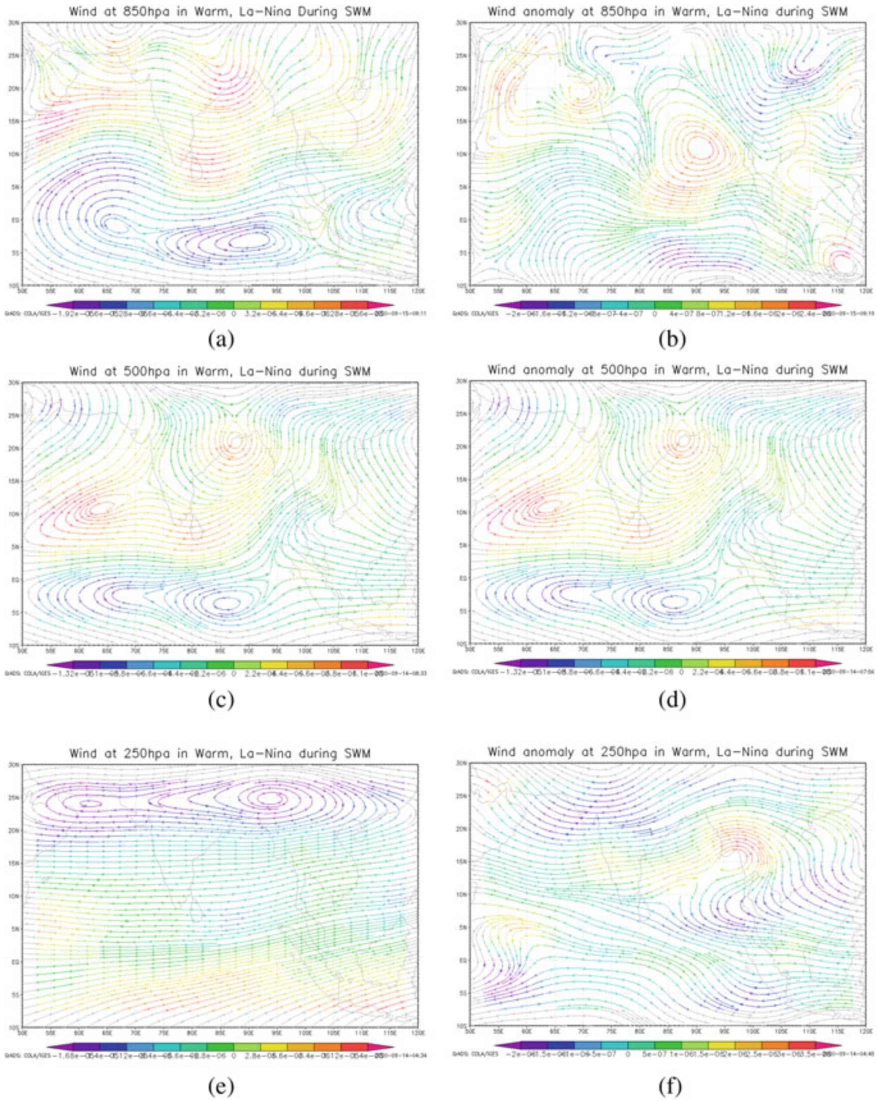


Fig. 3 **a** Wind at 850 hpa, **b** wind anomaly at 850 hpa, **c** wind at 500 hpa, **d** wind anomaly at 500 hpa, **e** wind at 250 hpa and **f** wind anomaly at 250 hpa in Warm, La-Nina during SWM period

4.2 Impact of PDO on El-Nino Signal During Southwest Monsoon Season

In the anomaly map of Fig. 5b it can be identified east west oriented anomalous ridge in 850 hPa overs the southern and eastern parts as well as 500 hPa over the western

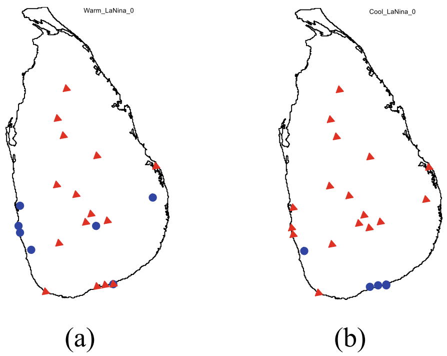


Fig. 4 **a** Dry and wet stations during La-Nina years when PDO Regime, **b** Dry and wet stations during La-Nina years when PDO Regime

and eastern parts of Sri Lankan region. The air is often sinking within a ridge and it tends to bring warmer and drier weather. Also there can be seen an anomalous divergence in 850 hPa layer in the north-east region of the Indian sub continent.

Anomalous cyclonic circulation appeared in north of Sri Lanka may have responsible for above normal rainfall over northern part of Sri Lanka during SWM, El-Nino episode during Warm regime of PDO. In Fig. 5f it can be seen that east west oriented anomalous ridge over the southern and eastern parts of Sri Lankan region and it tends to bring warmer and drier weather (Fig. 6).

Figure 7a shows that approximately 60% of the selected stations receives deficit rainfall in Warm, El-Nino episode.

In the Cool, El-Nino episode in the lower atmosphere north–east oriented anomalous ridge over the region closer to the south–east part of Sri Lanka and anomalous divergence can be seen in the western region of the Indian Ocean, these conditions are favourable for excess rainfall in the south western region and deficit rainfall in the south–eastern region.

In the wind anomaly map at 500 hpa level south-west oriented ridge is visible in the south-west Indian Ocean and it tends to bring wamer and drier weather to the south western part of Sri Lanka. Anomalous cyclonic circulation can be seen in the north of the Bay of Bengal at the upper atmosphere and it is favourable for excess rains in the northern region of Sri Lanka. Figure 7b shows that approximately 70% of the selected stations receives deficit rainfall in Cool, El-Nino episode.

5 Conclusion

Analysis was carried out to investigate the effect of PDO on the ENSO events. Considered SWM period has categorized as La-Nina—Cool PDO, La-Nina-Warm PDO, El-Nino-Cool PDO and El-Nino-Warm PDO. From the results obtain, it can be

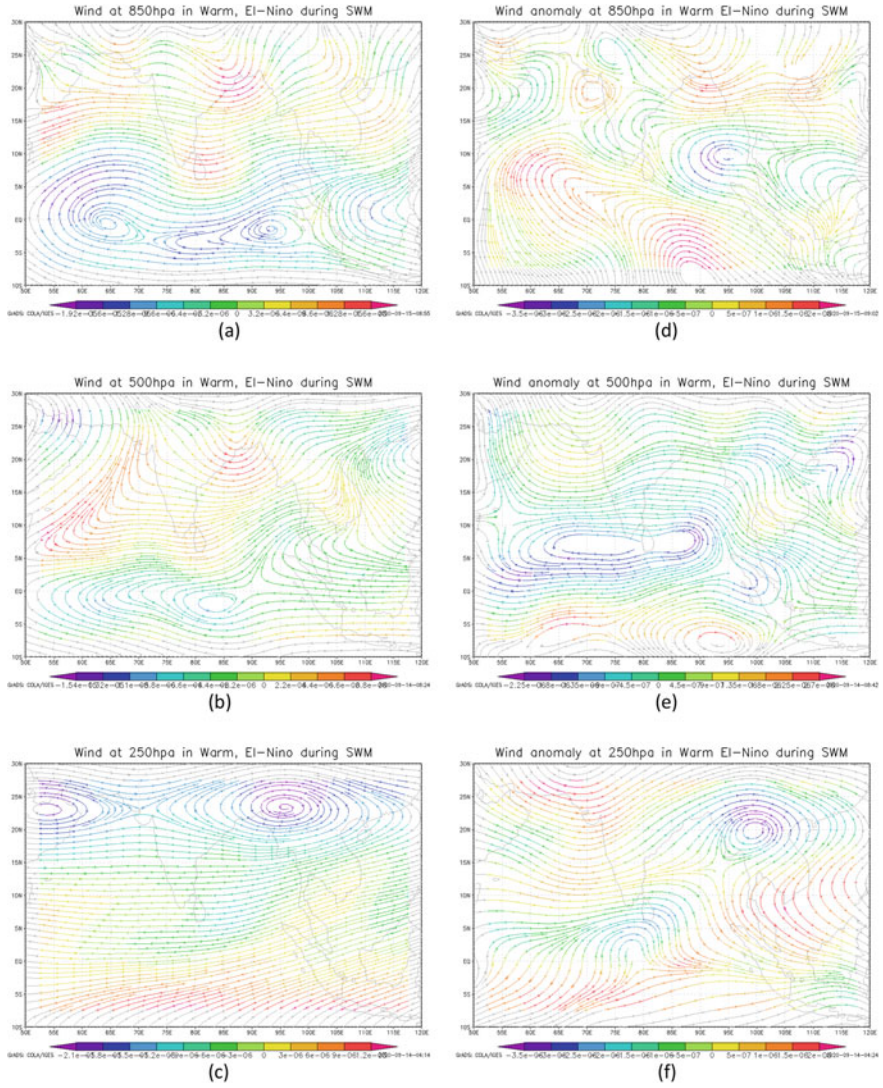


Fig. 5 **a** Wind at 850 hpa, **b** wind anomaly at 850 hpa, **c** wind at 500 hpa, **d** wind anomaly at 500 hpa, **e** wind at 250 hpa and **f** wind anomaly at 250 hpa in Warm, El-Nino during SWM period

seen that the Cool phase of PDO within the La-Nina episodes is related to enhance rainfall during SWM period over Sri Lanka. However, a reduction of SWM rainfall within the El-Nino episode, during both Cool and Warm regimes of PDO.

The relationship between SWM rainfall and ENSO event seems to be modified according to the regime of the PDO. The equatorial Pacific Ocean plays an intermediary role for this modification. The analysis provides a useful reference of when and

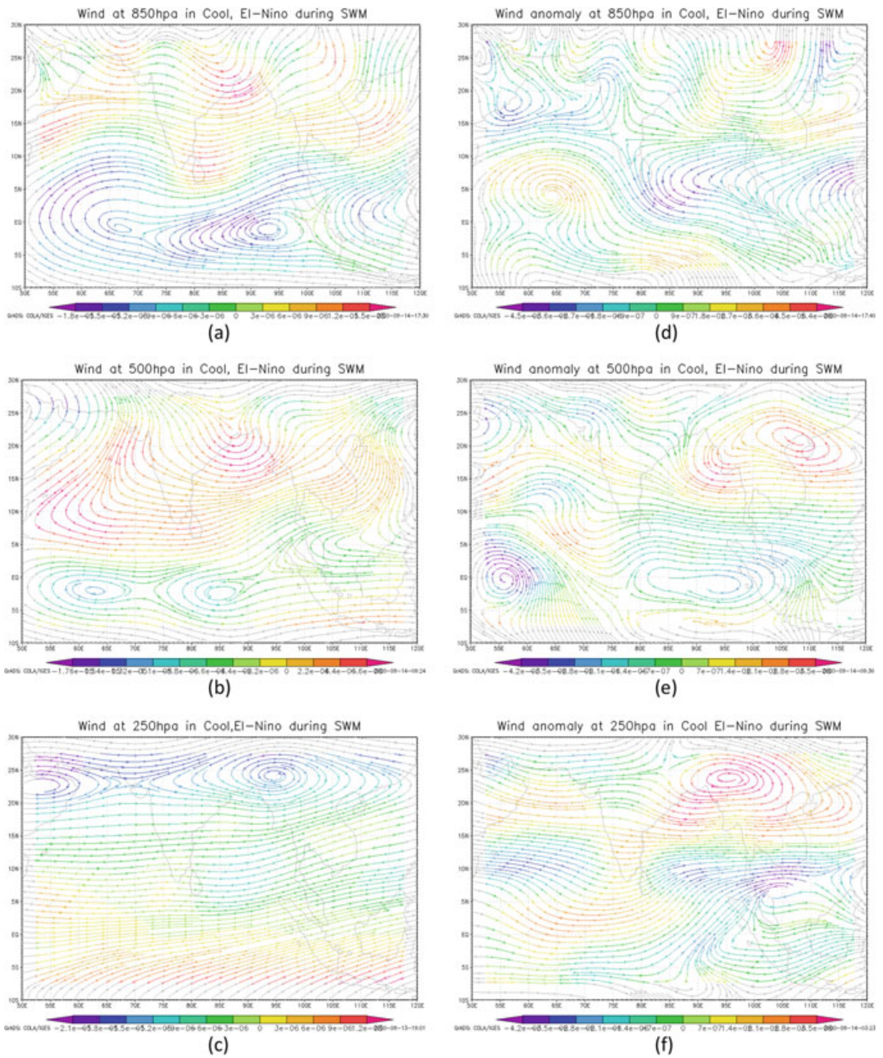
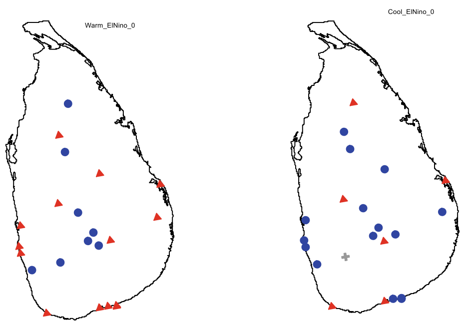


Fig. 6 **a** Wind at 850 hpa, **b** wind anomaly at 850 hpa, **c** wind at 500 hpa, **d** wind anomaly at 500 hpa, **e** wind at 250 hpa and **f** wind anomaly at 250 hpa in Cool, El-Nino during SWM period

where the PDO regimes have significant impacts on SWM period in Sri Lanka. This information can be used to enhance the skills of forecasting SWM in Sri Lanka.

A detailed analysis with more rainfall data is suggested to examine how SWM rainfall variations are associated with PDO regimes in Different ENSO events.



(a) (b)

Fig. 7 **a** Dry and wet stations during El-Nino years when Warm PDO Regime. **b** Dry and wet stations during El-Nino years when Cool PDO Regime

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Local Responsiveness to Changes in Climate: A Case of Underutilized Marine and Aquatic Resources

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Abstract Fish and seafood play an important role in the culturally diverse Sri Lankan consumer market while being a key supplier of essential protein to their diet. The island nation placed among the worst-hit countries of changing climate and adverse effects of it. The study attempts to find out the local responsiveness of fishery value chains to the climate shocks and prolonged changes. Rapid market chain analysis was performed in southern, western, eastern, and northwestern provinces which compressed of various agro-ecological zones of Sri Lanka to obtain the primary data. Results revealed that there are 13 of potential marine UUF species and 16 of inland UUF species. Both value chains were operated regionally in season and nature of chains were short, fragile, and less complex. Value chain actor concentration was high in both upstream and downstream ends and countable numbers placed in middle. UUF resources were recognized as a promising answer to mitigating the threat of dependency on a few commercial fish species while able to feed the local people in disaster lockdowns. Indigenous marine and inland species are moving into both local and international value chains ensuring employment opportunities and financial returns to local people. Fishery product diversification ensures wider consumer choices while supplying essential protein to the diet. Application of local knowledge on postharvest management and value addition opens up new avenues to female actors of fishery value chains.

Keywords Aquatic · Fish · Marine · Inland · Underutilized

1 Introduction

Climate change is one of the most earth-shattering topics and it has got the attention from the whole over the world without concerning the geographical, political, religious, economic and all other human-defined barriers in present. The extreme weather conditions such as heavy rainfall and snowfalls, long-lasting heavy drought

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conditions and hurricanes, continually challenge the entire world as rising the global temperature. Besides, the sea level rise, saltwater intrusion, drying off the freshwater aquifers results in strengthening the global hunger crisis, since the depletion of agricultural land and freshwater supply. Padulosi et al., (2013) has shown that there is an indirect relationship between climate change and the rise in hunger and starvation, poor health and rates of malnutrition, as well as the non-safe water. To mitigate these challenges requires an oracular move from the current practicing strategies towards sustainable alternatives that also place an equal benefit on human nutrition and health, as well as environmental sustainability (Francis et al., 2016). Climate change, variability and extreme weather events on food supply, access, affordability and security are recognized in Sri Lankan context as an important national issue (Esham & Garforth, 2013; Esham et al., 2018; Marambe et al., 2015). Climate-induced issues act as a great barrier to local food supplies. Reduced quality and quantity of harvest, losses along the supply chains, poor access and affordability of food for poor segments of the communities, the prevalence of under and malnutrition were main threats on livelihoods. As an island nation, Sri Lanka is also struggling to identify the possible opportunities and alternatives to feed the community to evacuate from the dark shadow of the climate change. Crop production systems are central in building climate-resilient food production (De Costa, 2010). Fish and livestock production systems were excluded or ignored by the current resilient building mechanism. Holistic approach inclusive of crop, fish and livestock production systems would strengthen the climate resilience actions of Sri Lanka. In the context of a fishery, there is a big treasure still preserving for us to take a significant shift as a response to the hunger crisis with sustainable utilization of nutrient-dense marginalized food fish species. Underutilized fish (UUF) is currently playing a vital role in rural food and nutrient security of Sri Lanka. Only a handful of researchers pay their attention to investigate the potential strategic interventions through UUF. Hence the current study is scoping on the marine and inland underutilized fishery and its value-chain characteristics.

The Sri Lankan fisheries sector has been played a considerable role in strengthening the country's economy. Per capita fish consumption of the country is 15.8 kg per annum and 8.4% of household expenditure spent on fish (DOF, 2018). Importantly, 70% of the animal protein requirement of people in the country is provided by the fisheries sector (Amarasinghe, 2014). Further, the country used to import a considerable amount of fish and fishery products to fill the gap. It is an urge to start to break the wall of a focused fishery system to build up a sustainable fishery management system by giving equal value to marginalized under-utilized fish species (UUF). A UUF species can be defined as a fish that has a low commercial value by under their low perceived quality, small size or low consumer preference relevant to the scope of the present study (Witkin, 2014, Hall, 2011). These fishes are sometimes referred to as trash fishes or underappreciated species (Witkin, 2014). The trash fish label is tagged on the UUF due to most they are caught as by-catch of the target fishing efforts (FAO, 2005; Batista, 2006). Consequently, they have poorly exposed and understood the value-chains of this fishery which varies across geographic and socio-economic settings. Several research findings have advocated for their use as a part of sustainable fisheries techniques that speak to adaptation, mitigation, and sustainable intensification of production systems.

The target species fishing practices which are currently prevailing all over the world have a huge negative impact on the marine and freshwater ecosystems (Pauly et al., 1998). Subsequently, the mean trophic level of fish caught in marine and inland areas gradually fall off (Pauly et al., 1998). Kelleher (2005) has shown that the estimated worldwide marine fisheries make 7.3 million Mt of trash catch annually and many of these fish, though not landed do not reenter the ecosystem to reproduce. If these by-catch stocks can be marketed in place of target species, fishing pressure on target species may be reduced as consumers shift their preferences. The demand for marine fish is mostly aggregated around the coastal and urban areas whereas, a considerably higher proportion of the country's poorest and malnourished communities, especially undernourished children (IPS, 2010), reside in rural inland areas of the dry zone and their demand rely on locally available freshwater fish (Murray et al., 2000). Therefore, the role of the UUF spread over different socio-economic aspects such as enhancing the resilience of livelihoods of the poorest segment of the community, supply nutritionally improved fish food (Amarasinghe, 2014; Arunatilake et al., 2008). Besides, it provides answers to the issues of market-oriented marine and inland fisheries such as high cost of production, low and fluctuating and seasonal catch, heavy dependency on few commercial species, and hiatus of diversity in nutrition and meals (Batista, 2006). In general, UUF compatible with the local climatic conditions especially resilient on changing climate (especially drought, flood, etc.) (Witkin, 2014) while matched with local/traditional knowledge.

Food and nutrition security of the inhabitants is vital in all development programs and especially capacity building and empower people against climate risks. Whereas, they were still stuck on their halfway without accomplishing their goals owing to the insufficient insight of current market conditions and value-chain characteristics of Sri Lankan fishery. Therefore, this study would address the value-chain characteristics of Sri Lankan under-utilized fishery to give an insightful discussion about enhancing UUF as a strategic local response for the global climate change crisis.

2 Methodology

The methodology adopted in this study comprises three analytical stages. First step was to identify the suitable UUF species. Second based on rapid market chain analysis and the identification of prevailing fishing and post-harvest processing techniques for selected underutilized food fish species in both marine and inland sectors and the final stage was value chain analysis of UUF. The sites included in this study were the main fish landing sites of southern, western, eastern, and northwestern provinces of Sri Lanka. The research team collected both primary and secondary data using different data collection methods and tools; structured questionnaires and interview guides supported field surveys, an in-depth interview, focus group discussions and verifications through telephone calls and site visits. For the marine fishery sector,

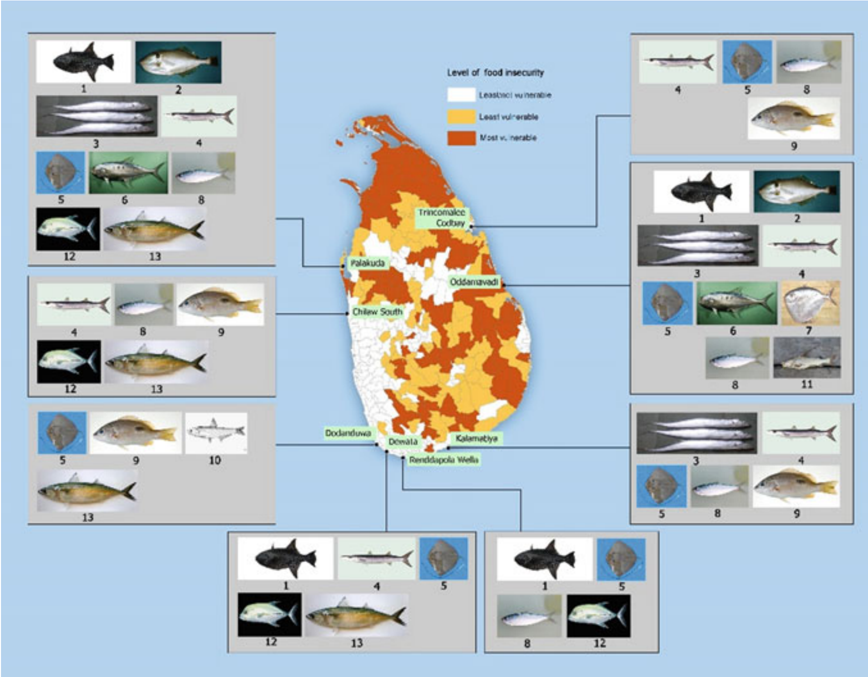

Fig. 1 Distribution of Marine UUFs over the food insecurity index of Divisional Secretariat Divisions; the fish species numbers as 1—*Canthidermis maculate,* 2—*Aluterus monoceros,* 3—*Lepturacanthus savala,* 4—*Sphyraena jello,* 5—*Dasyatis sp.,* 6—*Scomberoides sp.,* 7—*Mene maculate,* 8—*Sardinella gibbosa,* 9—*Lutjanus fulviflamma,* 10—*Thryssa encrasicholoides,* 11—*Nemapteryx caelata,* 12—*Caranx sp.,* 13—*Rastrelliger kanagurta.* Map source: Zubair et al., (2006)

there were 9 different fish landing sites were selected (Fig. 1) based on the industry performances and the key informants were Fisheries Inspectors (FIs) and District Fisheries Officers (DFOs), administration officers of DFO, and members of fisheries societies. For the inland fishery sector, there were 5 perennial and minor perennial reservoirs were selected to cover the key inland fish production sites in the dry zone of Sri Lanka (Fig. 3). The informants of the inland sector were regional extension officers of the National Aquaculture Development Authority (NAQDA) (Fig. 2).

3 Results and Discussion

Fifteen marine fisheries districts are located around the country while the marine fish production generates about 50% of the annual production (volume, species, post-harvest handling, and marketing) is varying enormously among districts. Lead producers were Tangalle (15%), Puttalam (14%) and Galle (10%) districts had dominated marine fish production (DOF, 2018). Results revealed that there are 13 potential

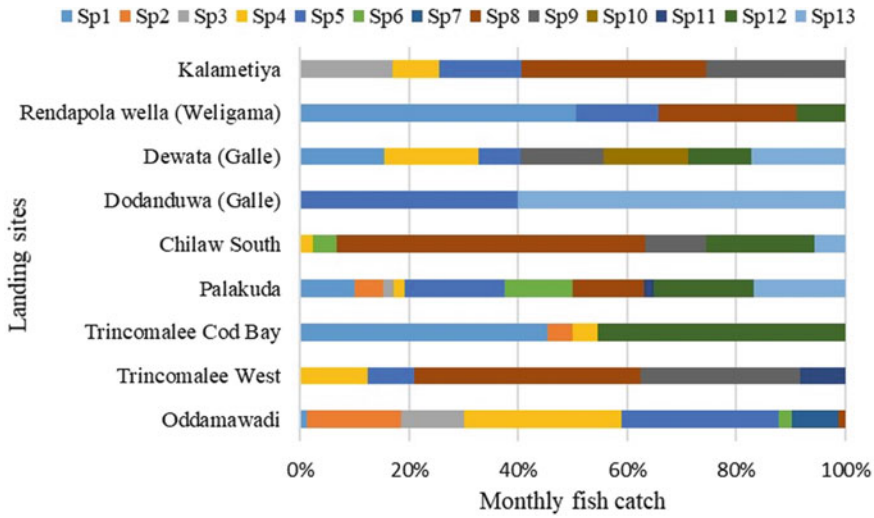

Fig. 2 Marine UUF fish catch composition in marine landing sites. The fish species are numbered as in Fig. 1. *Source* Catch logs of regional Marine Fisheries Inspectors

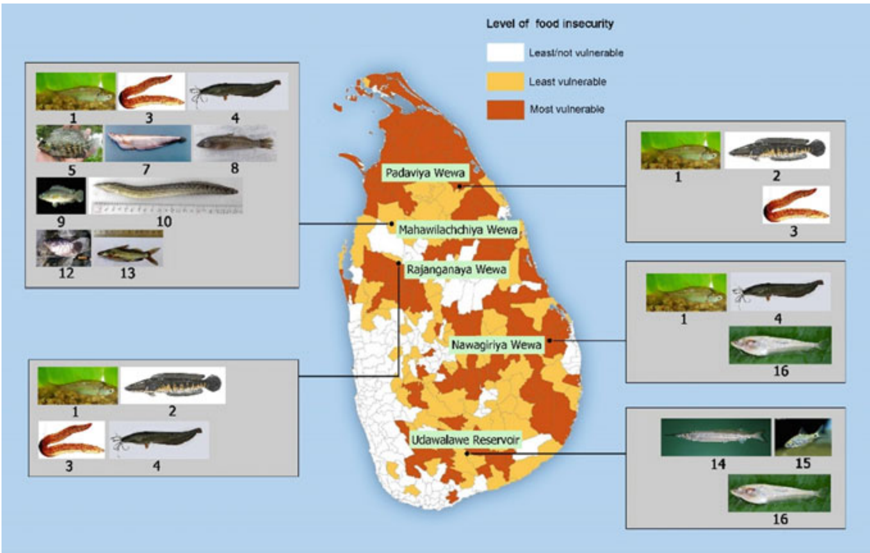

Fig. 3 Distribution of Inland UUFs over the food insecurity index of Divisional Secretariat Divisions; the fish species numbers as 1—*Amblypharyngodon melettinus, 2—Channa striata, 3—Anguilla sp., 4—Heteropneustes fossilis, 5—Etroplus suratensis, 6—Puntius layardi, 7—Wallago attu, 8—Awaous grammepomus, 9—Anabas testudineus, 10—Mastacembelus armatus, 11*—Ompok *sp., 12—Osphronemus goramy, 13—Mystus vittatus, 14—Hyporhamphus limbatus, 15—Puntius Dorsalis, 16—Ompok bimaculatus*. Map source: Zubair et al., (2006)

marine UUF species (Fig. 1). Fish catch of UUF species was varied location wise and seasonally. Catch variations were significantly affected on market availability, price fluctuations and processing of UUF. Climate and seasonal variations were identified as important reasons behind the catch variability (Arunatilake et al., 2008; Edirisinghe et al., 2018; Murray et al., 2000).

3.1 Marine Underutilized Food Fish Species

Most of these UUFs were not recorded in species level and instead, they were recorded as whole catch of other species. Interestingly, most of the marine UUFs are identified in food insecure areas of the country. Further, they were not considered as targeted fish. The most common UUF species of the studied areas were *Lepturacanthus savala* (Sawlaya), *Dasyatis* sp. (Madhuwa), *Canthidermis maculata* (Pothubari/ Muhudu Kukula), *Caranx* sp. (Lena Paraw), and *Rastrelliger kanagurta* (Kumbalawa). Besides *Aluterus monoceros* (Siviya) in the eastern province, *Scomberoides* sp. (Kattawa) in the western province and *Lutjanus fulviflamma* (Ranna) and *Ablennes hians* (Moralla) in the southern province were notified as other regionally common UUF species (Fig. 2). Fisheries sector is renowned for its culture, traditions, crafts and gear, fishermen and women and especially the tropical multi-species fishery. The traditional fisheries industry is considered inefficient in terms of economic gains but it maintains the social and environmental perspectives towards sustainability. On the other hand, the modern fisheries industry is planned to achieve economic success through efficient crafts, gear, volume catches and profits to fishermen. Unfortunately, modern fishing gears are beyond the affordability of small-scale fishers (Silvestre et al., 2003). Category of UUF caught from various means; by-catch, a component of tropical multi-species fishery, trash fish, etc. and recorded from both marine and inland waters. Heavy dependency on few selected commercial marine species and a countable number of inland commercial species has created a huge gap between demand and supply of fish. Unintentionally, fishers move towards to nontraditional or less popular species to bridge the gap. In addition to that composition of fish, catch varies regionally and seasonally where different communities have their own food fish culture. Most of the nontraditional or underutilized species consume, process and market in a unique way which is ignored in common literature.

3.2 Inland Underutilized Food Fish Species

There were 16 of the inland UUF species identified over the studied 5 fish landing sites. *Amblypharyngodon melettinus* (Wew Salaya) was recorded in 4 study sites and catch volumes were comparably high. Besides, Aanda (*Anguilla sp.*), Hunga (*Heteropneustes fossilis*), Lula (*Channa striata*), and Walapoththa (*Ompok bimaculatus*) species were other common types (Figs. 3 and 4). Thus, 70–95% of the total

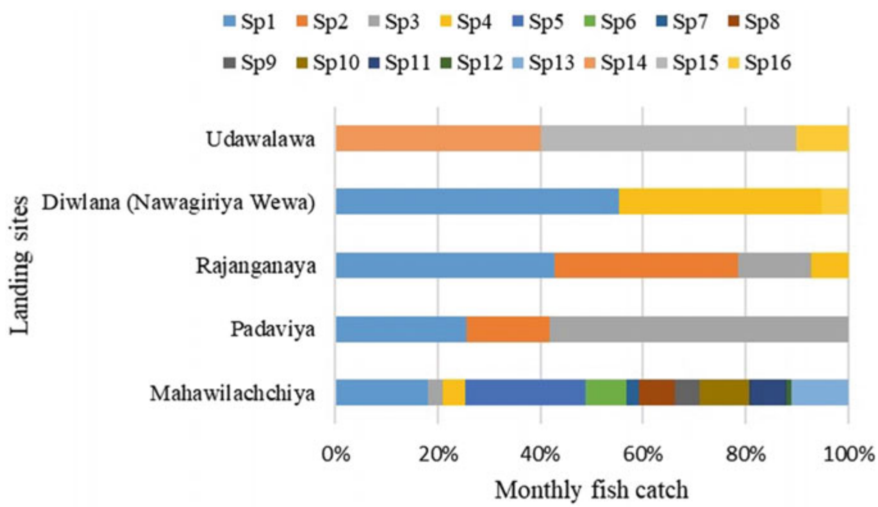

Fig. 4 Inland UUF fish catch composition in landing sites. The fish species are numbered as in Fig. 3. *Source* Catch logs of regional extension officers of NAQDA

inland fishery yield is provided by tilapia *Oreochromis mossambicus*, and its hybrid with *Oreochromis niloticus*, as playing a vital role in providing of low cost, high-value food to the rural poor. Besides, Murray and Little (2000) showed that the tilapia fishery utilizes only a small share of the existing fish biomass in reservoirs. Hence, the other two strategies are recommended as the exploitation of untapped native minor cyprinids and the second on the enrichment of their fisheries via culture-based fisheries management. Once such a fishery system is introduced the utilization levels should be closely censored to govern the finest fishing approaches (De Silva, 2008).

Out of 30 indigenous species 15 species are considered food fish species whilst out of the 6 species are caught in considerable volumes (De Silva, 1988). Concerning to previous research, (Amarasinghe, 1990; De Silva & Sirisena, 1987; Kumara et al., 2009) identified the small-sized cyprinid species such as *Amblypharyngodon melettinus*, *Puntius chola*, *Puntius dorsalis* and *Puntius filamentosus* (minor cyprinids) showed better potentials. Further, the research highlighted that these species can be differentially harvested using small-mesh (<52 mm stretched mesh size) gillnets without harming the existing reservoir fishery based on exotic cichlids. Compare to the yield of the tilapia fishery, some studies have assessed the potential minor cyprinids yield of 250–300 kg/ha/year (Murray & Little, 2000). *A. melettinus*, is mainly fed on phytoplankton which is the most abundant food source in water bodies (Hofer & Schiemer, 1983). Roos et al., (2007) reported that small native fish species in the South Asian region have considerably high potential for causal to human nutrition, owing to the reason that some small fish species such as *Amblypharyngodon sp.* are found to be rich in vitamin A.

As the dry season advancements, most of the fishers were use mesh sizes well below the legal requirements, 3.5 inches mesh, for targeting not only small tilapias but also other indigenous species with a variety of minor cyprinids. At this time *A. melettinus* are harvested by using 3/4″ nets. Most of migrating indigenous species catch takes place during the tank spilling period from November to January (Murray et al., 2000). Traditionally the villagers use traditional gears, Kemana and Karakaya for fishing in these spillways as an effective method. Owing to the low abundance and the dwelling habits, the larger secondary consumers, *Anguilla sp.*, Wallagu attu and *Channa sp.* yield comparably low. These predatory species' volume only second to the tilapia production and they are extremely adjusted to conditions in small perennial and minor perennial reservoirs. Beside they are representing a possible niche production area within existing culture-based fishery (Murray et al., 2000). The drought-resistant air-breathing snakehead *Channa striatus* could diminish the occurrence of inhibition associated with congestion (Murray and Little, 2000).

3.3 Underutilized Fish Value Chain

The value chain approach has been considered as a promising tool to investigate the specific challenges facing a sector resulting from various drivers of change, including climate (Macfadyen & Allison, 2009; Curtis et al., 2011; CABI, 2008). Critically, such analyses can reveal context-specific response strategies to enhance a sector (Jacinto et al., 2011). A value chain is defined as the full range of activities which are required to bring a product or service from conception, through the different phases of production, delivery to final consumers, and final disposal after use (Kaplinsky & Morris, 2001). A value chain approach can be used to examine the network of actors and their roles to deliver the value (Basnayake et al., 2018). A value chain analysis is particularly appropriate to understand the far-reaching effects that climate change will have on fisheries and aquaculture, a method of producing highly dependent upon inputs such as seed, feed, and freshwater (Curtis et al., 2011).

Climate change and variability are expected to have significant negative effects on the livelihoods of the people (Magrath, 2008; Hepworth & Goulden, 2008). Specific adaptation strategies need to mitigate the effects and provide effective options to improve livelihoods (Allison et al., 2009). Both commercial and small-scale fishery value chains act as raw material suppliers to fish processing, especially the dry fish sector (Sugathapala et al., 2012). Upstream of dry fish value chain begins from commercial and small-scale fishers as input suppliers and downstream with large number of consumers. UUF value chains are shorter, few nodes in its design architecture, and operate regionally. Figure 5 explains the marine (in pink) and inland (in blue) UUF value chains. Mid-stream represents the fish processors (mainly dry, salted, smoked and Maldives fish) and traders (local collectors and wholesalers). Dry fish producers maintain various arrangements to assure the raw fish supply. Processors obtain fish from auctions in landing sites and usually, second grades used for processing and peak processing season are in line with the main fishing season (Murray et al., 2000). Local collectors and traders collect processed products

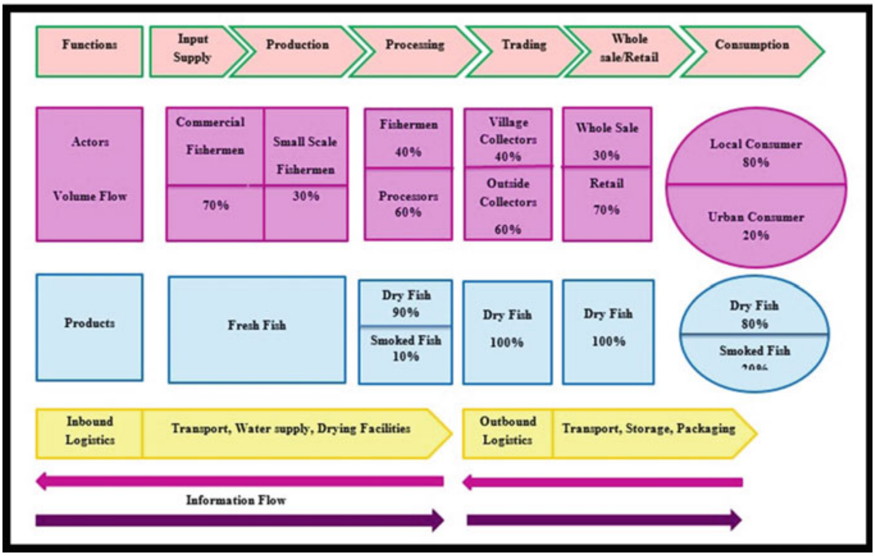

Fig. 5 UUF value chain

through establish networks. Fish processors usually the price takers with poor price bargaining power and maintain poor relationships with end markets.

Mid-stream is playing a strategically important role in providing logistics facilities and deliver products to end markets. Local collectors and traders have their arrangements to secure processed fish supplies. Downstream connected to customers and their role is essential to promote the UUF among customers. Fresh and processed UUF receives poor market attention compared to marine fishery products and usually fetch low prices (Tissera, 2011). Between the period of July–September (dry season) considered as peak inland production season where fresh fish prices tagged lowest and dry fish processing reach its highest level. Regional circulation of UUF mainly due to low demand and lack of consumer preference for inland species discourage middlemen to bear long-distance refrigerated transport costs (Murray et al., 2000). Fisheries legislation and regulatory issues, access to capital (boat and fishing equipment, storing facility, and transport), prior experience, knowledge and knowhow on efficient fishing methods and social background were identified as entry barriers to both marine and inland UUF. Therefore, UUF value chain upgrading essentially need to remove the entry barriers and making market space for new entrants. Introduction of appropriate processing technology for local fishermen is vital to secure the extra harvest of peak fishing season. Value flow of the underutilized processed (mainly drying) deliver the value added to its end users and top gainers were Siviya, Sawalaya, Maduwa, Katta, Panno, & Salaya. Further, value chain of inland sector was shorter compared to marine sector and promising UUF species for better returns were Lula, Hunga, Korali, Katupethiya, Kawaiya, Gurami, Maranda, Ambaya, Walapoththa.

4 Conclusions

Fisheries industry contributes significantly to Sri Lanka's national economy and food security. Both marine and inland fisheries sectors are vulnerable to climate change, variability, and additional non-climate related drivers of change, rapid population growth, socio-economic issues, legal aspects, local and global political situation and environmental aspects. Value chain analysis is a useful approach to identify a sector's challenges resulting from various drivers of change, including climate. The impacts of climate change on Sri Lankan fisheries result from an increase in mean air temperature, shifting rainfall patterns (shift in monsoon seasons), increase the intensity of rainfall and an increase in extreme weather events (cyclones, droughts, floods, tornados, etc.). Marine fishery value chains are relatively well developed compared to the inland fishery value chain. UUF species of promising features were identified in both marine and inland fisheries but value chains were underdeveloped, shorter, and less complex, few actors involved and cater only to the local demand. Both marine and inland fisheries sectors depending on few commercial species, and both value chains were impacted by climate change and variability in similar ways related to production, processing and transport. UUF species were identified in both sectors as a promising replacement, which helps to secure rural food and nutritional security. Dried, smoked and slated value-added forms were common in UUF value chains where the excess catch of peak fishing season and second grade fish were used for processing. Traditional processing techniques were common in all locations, and family labour, especially females handle the processing work. Local collectors and traders bridge the upstream and downstream of the value chain. Shorter value chains were operating locally and a negligible amount of processed fish moved to urban markets. Value chain upgrading factors were identified and key aspects were unity, trust, respect among fishing communities, awareness on processing, handling, storage, hygienic and food safety practices, adapt to modern and appropriate technology, concern on environmental, produce value-added products, innovative practices/products, and away from malpractices. Considered constraints were Monetary (costs for operations, fuel, legislation, and repairs), Legal (rules and regulations), Human resources (availability of skilled workers), supplies (equipment and repair tools), Market accessibility, and Climatic disturbances.

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Natural Versus Manmade Disasters: Impact of Disasters on Small Holder Agricultural Systems in Gem Mining Areas of Sri Lanka

M. S. Elapata and D. Achini M. De Silva

Abstract Natural versus manmade disasters are frequent incidents which devast the livelihoods of gem mining areas. The study attempted to investigate the impact of both natural and manmade disasters on livelihood assets of small holder artisanal agricultural systems in main gem mining area of Sri Lanka. Institutional analysis performed to identify and develop the institutional landscape which manage and govern both agriculture and gem mining. Land use maps were instrumental to identify the land use pattern, crop typology and disaster risk prone areas of the gem mining areas under study. Field survey strategy was used to investigate the people component of the study. Un-sustainable and illegal mining operations were directly linked with occurrence of frequent floods and landslides in the study area leading to soil erosion, sedimentation, removal of vegetation. Livelihood asset vulnerabilities were high among the small-scale artisanal farm households. Coping strategies were developed to mitigate the disaster risk and manage the vulnerabilities of small-scale artisanal farmers.

Keywords Disasters · Gem mining · Small holder agriculture systems

1 Introduction

Disaster is defined as a destructive event relative to the resources available and makes casualties which cause an impact to the society for a short period of time (Alcántara-Ayala, 2002). Disasters could be classified as natural, manmade and hybrid. Disasters are largely unavoidable with the growing threat of climate change. Sri Lanka being an island experiences both natural and manmade disasters as in many other countries. The seven most frequently reported natural disaster events in Sri Lanka ranges from floods, extreme wind events, landslides, lightning, droughts, animal attacks and fires (Amarasinghe, 1999). Sri Lanka is an island bestowed with two main monsoons namely the southwest and the north east monsoon (Jayawardane, 2006). In general,

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monsoons are responsible for floods in many parts of the country and the south-west monsoon causes the flooding in the Western, Southern and in Sabaragamuwa Provinces. As a result, Rathnapura district which is one of the main gem mining areas of the country is prone to both floods and landslides frequently. However, an increase in flood frequency has been observed in the basin in recent years, as recorded by the online database, Disaster Information Management System. Apart from the natural hazards caused by climate change, manmade disasters are common in Rathnapura district namely artisanal and commercialized, gem mining and sand mining. Artisanal and small-scale production is informal in nature and is based on traditional technology (Amarasinghe, 1999). Mining has resulted in soil erosion and sedimentation in river bed and had negatively affected on the irrigation efficiency, thus making floods and landslides common within the areas (UNDP, 2017). Sand mining from river bed and river bank sand deposits has also increased greatly in Sri Lanka (Piyadasa, 2011). This had resulted in heavy localized turbidity, lowering of water tables, river bank erosion and land degradation resulting in hardships, both to agriculture and food security (Piyadasa, 2011).

Agriculture being the livelihood of most of the rural people in developing countries faces a hard hit from disasters (Chapagain & Raizada, 2017). Agricultural production is highly dependent on weather, climate and water availability, and is adversely affected by weather and climate related disasters (Sivakumar, 2014). It is widely recognized that the agricultural sector is vulnerable to natural disasters and other extreme weather events as it the hit local production and availability of food, contributing to rising food prices and destroying local livelihoods (Nguyen, 2016). The floods that affected Sri Lanka in 2016 widespread negative impacts on the agricultural production and was estimated at about USD 2.6 million in damage (Conforti et al., 2018).Disasters are further aggravated by the human activities and operations which disturb the natural balance of the ecosystem. Thus, the poorest and the economically and socially vulnerable farmers were those most at risk due to the aftermath of disasters (Chapagain & Raizada, 2017). Thus, it is important to identify and record the actual impact of these disasters both natural and manmade disasters on the small holder's agriculture systems in overexploited gem mining areas in Sri Lanka. The study specifically investigated the impact of natural and manmade disasters on the livelihood assets; social, physical, financial, human and natural of the small holder artisanal agricultural systems in gem mining areas and thereby identified the barriers to minimize these impacts and propose mitigation strategies. Figure 1 explains the conceptual framework of the study. Climate change, artisanal and commercial gem mining and sand mining are the root causes for the natural and manmade disasters in gem mining areas. The natural versus manmade disasters have impacted on the livelihood assets of the small holder agriculture systems whereby it disturbs the natural ecosystems and the small holder agricultural or production systems and finally exacerbating social disturbances. Thus, the smallholders' awareness on the negative impacts of disasters were studied through this exploratory research.

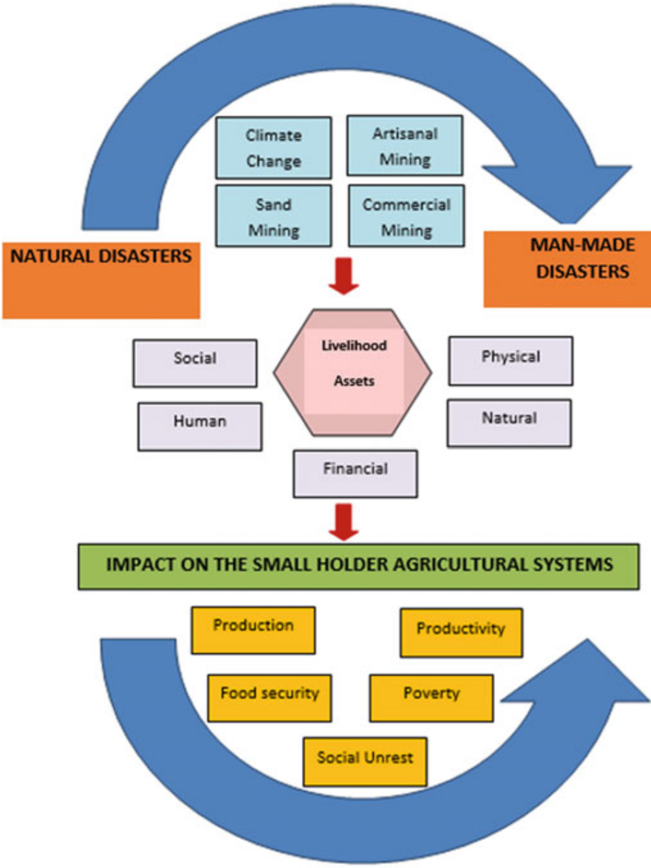

Fig. 1 Conceptual framework

2 Methodology

The records of NBRO (2017) identifies seven districts of Sri Lanka including Rathnapura as a district highly vulnerable for disasters. Thus, the study was carried out in the Elapatha DS division of Rathnapura district which is an area highly vulnerable to disasters and also and area badly affected by excessive gem and sand mining. The study was carried out in the Elapatha DS division of Rathnapura district where 3 GN divisions were selected purposely based on severity of the impacts including Elapatha, Pallegedara and Dellabada out of the 21 GN Divisions. Focus group discussion and survey strategy were adopted for the data collection. A sample of 100 farmers were selected using simple random sampling to conduct the preliminary field survey. Further, a focus group discussion was conducted with 20 farmers representing the 3 GN divisions. Further, in dept interviews were conducted with the officers of the

Department of Agriculture, Ministry of Disaster management and DS of Rathnapura. Secondary data were obtained from the Department of Agriculture, Ministry of Disaster management and DS of Rathnapura. The focus group discussion was instrumental on questions pertaining to impact of both natural and manmade disasters on the livelihood assets and the impact on the small holder agricultural systems. Both qualitative and quantitative techniques were instrumental to analyze the data. Further, the social mapping, Institutional analysis, maps of occupational and seasonal trends were developed based on the available data. Land use maps of the areas were used to identify the main crops and the mining sites in the location.

3 Results and Discussion

3.1 Natural Disasters

Study locations; Elapatha, Pallegedara and Dellabada, experienced disasters regularly, both natural and manmade. Sample profile is summarized in Table 1. Floods and landslides are the common natural disasters experienced by the farmers in this gem mining areas. Figure 2 depicts the major disaster timeline for Rathnapura district. The flood occurrence trend revealed that there is an increase number of flash floods in the recent years compared to the days of yore. Further the farmers revealed that

Table 1 Sample profile

Criterion	Elapatha	Pallegedara	Dellabada
Mean annual rain fall	3679 mm	3679 mm	3679 mm
Mean annual temperature	27.1 °C	27.1 °C	27.1 °C
No. of households	525	367	775
No. of registered farmers	450	104	226
No. of artisanal gem mines (functional)	30	14	10
No. of sand mines (functional)	02	01	01
Agriculture holdings			
a. Paddy (acres)	83	66	116
b. Tea (hectares)	24.53	10.47	26.74
c. Rubber (acres)	263.14	20.2	311.1
Mean income level (% of farmers receive an income less than LKR 20,000 (Based on the survey data) Official poverty line at national level for January 2020 is Rs. 5021	73%	64%	75%

Source Elapatha Divisional Secretariat/Elapatha Agrarian Service Center

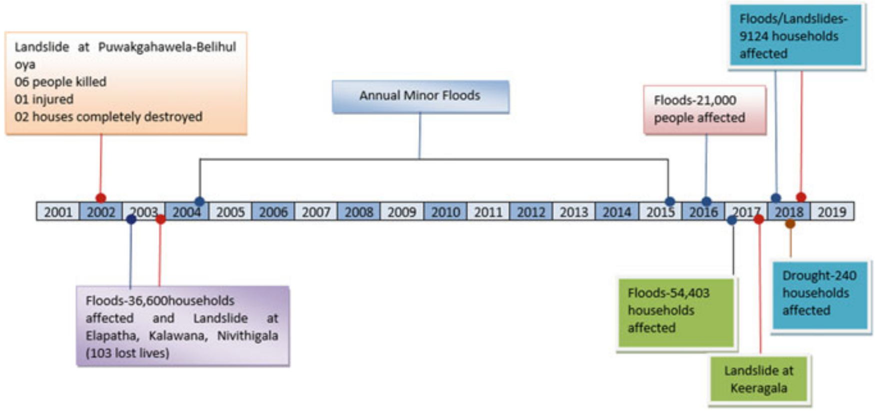

Fig. 2 Timeline of the natural disasters

even droughts are being more common in the study location despite being a region in the wet zone of the country.

3.2 *Manmade Disasters (Artisanal Gem and Sand Mining)*

The farmers revealed that excessive involvement of plantation mainly tea, mining including both artisanal and mechanized gem mining and sand mining in rivers are the main precursors of the manmade disasters in the area. The farmers revealed that the removal of the natural vegetation and replacing them with the cultivation mainly tea in the areas has caused soil erosion. This condition is aggravated due to the presence of poor land management practices in the tea lands such as no lateral drains, poorly managed weed cover, etc. Thus, the soil is subjected to the action of rain and become loose enough by causing erosion. This had been one reason for the vulnerability of landslides within the study area. Figure 3 reveals that onset and offset of the main

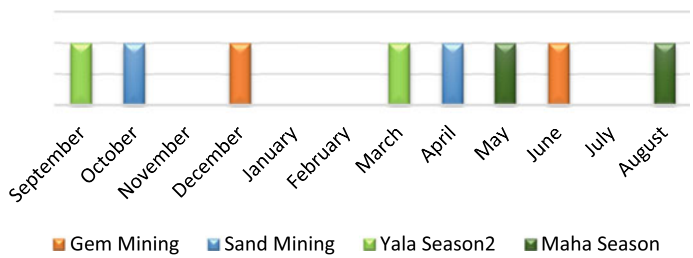

Fig. 3 Annual events: onset and offset of the seasons

agricultural seasons and the gem and sand mining seasons of the study area. This highlighted that gem and sand mining is a regular activity of the area.

Artisanal mining is based on manual tools and equipment but limited use of power, energy yet a labour intensive industry. This is usually carried out by the farmers as a part time occupation, laborer, when the agricultural workload is at a minimum and off season for paddy. Study revealed that 90% of the labor engaged in the gem industry is farmers. A pit mine, usually consists of a vertical shaft that measures two by four meters whereas the depth of a pit could range up to 50 m. However, the focus group discussions of the agricultural instructors and the farmers revealed that apart from the registered mines, in the mining take place in illegal forms which has no records. On contrary there is considerable amount of mechanized mining within the area. Mechanized mining use backhoes or excavators to remove the soil. Open pits are then filled with rainwater that has to be pumped out before mining could continue. Using excavators in gem mining has many negative impacts on the natural environment. However, the farmers revealed with the emergence of mechanized mining, the area is now prone to drought conditions as the water table is heavily disturbed. Even though the government granted a limited number of permits to use excavators and backhoes in mining operations illegal mining operations devastated the area including the farm lands. There should be a proper monitoring and law enforcement mechanism is essential to control the illegal operations.

Results revealed that mining was one of the major reasons for the occurrence of frequent floods and landslides in the study area. Mining both artisanal and mechanized, causes damage to natural vegetation, plantations and paddy fields. Further, degradation of the land, damage of streams and river banks, soil erosion and epidemics were negative results of the abandoned mining pits. Environmental pollution is due mainly to washing schist near streams and scattering debris from the schist into soils were identified as unethical mining operations. It has also been found miners leave their soil heaps around the mines. The rains and floodwater also carry the sand, silt and clay to the nearby streams, rivers and low-lying areas or paddy fields causing problems of sedimentation. The deposition of sediments blocks the streams and canals. Heavy sediment deposition raises the stream beds thereby reducing the capacity of rivers to absorb flood waters. Unplanned gem mining with less concern on nature had created an increased risk of landslide threat in steep slopes and also favorable conditions for floods. Further, field observations highlighted that damage caused by commercial mining was severe than the damage from artisanal mining. In one hand, irresponsible miners neglect the regulations on mining process, especially the winding up of the mine. On the other hand, irresponsible government officers who were responsible to oversee the operation were paid poor attention on implement the law and order. Apart from gem mining study area is subjected to sand mining operations too. Illegal sand mining was carried out extensively in rivers and streams. Heavy mechanical equipment such as long arm backhoes and motor boats are used in sand extracting. The removal of the sand layer in rivers had brought serious impact on the groundwater availability. Many agricultural crops usually cultivated along the river banks were failed due to the unavailability of water and had drastically decreased productivity of crops especially paddy in the Maha season. Sand mining in areas with steep slopes can create bed scouring, siltation, change of river, bank erosion, and thereby triggering landslides and floods. Thus, gem and sand mining, were recognized as critical man-made disasters which had exacerbated the threat of more frequent occurrence of natural disasters within the area. Mechanized sand mining also causes huge damage to the riverine environment and ecosystem. Further, the opinion of farmers revealed that ignoring proper rehabilitation methods and poor water management in low country tea plantation were also regarded as contributory factors for unstable slopes and landslides. Rubber was the key plantation crop of the area and that was overtaken by tea and cinnamon. Further with the fall of the rubber industry, smallholders opted for shifting away from rubber to cinnamon and tea. Thus, uprooting of rubber trees without proper land management has creating loose soils and thereby increases in water infiltration exuberating landslides. Most of the small holders ignore the land management practices due to heavy capital investment and poor land management is another threat.

4 Impact of Disasters

Disasters brought negative externalities for both farmers and their agricultural systems in terms of social, economic, environmental, physical, and human capital aspects. A social mapping exercise was carried out in the research locations. Maps were able to identify and locate the agricultural lands, gem and sand mining areas, government institutions, village boutiques and rice mills, disaster prone areas of the study location as shown in Fig. 4.

Livelihood assets analysis was carried out to identify the impact of the natural and manmade disasters on social, human, financial, physical, and natural capital.

4.1 Impact on the Social Assets

Results revealed that the disaster in general, both natural and man-made place the lives of the farmers in vulnerable situations and exposes them to numerous risks and dangers. Constant displacements and relocations, disruption of education of their children, health risks, psycho-social and protection issues, are some of the major challenges faced by those affected. This has thus caused social unrest within the people. Further, illegal gem and sand mining using heavy machinery has already created social unrest among the community groups, and weak enforcement of law and authority. The impact of social assets is summarized in Table 2.

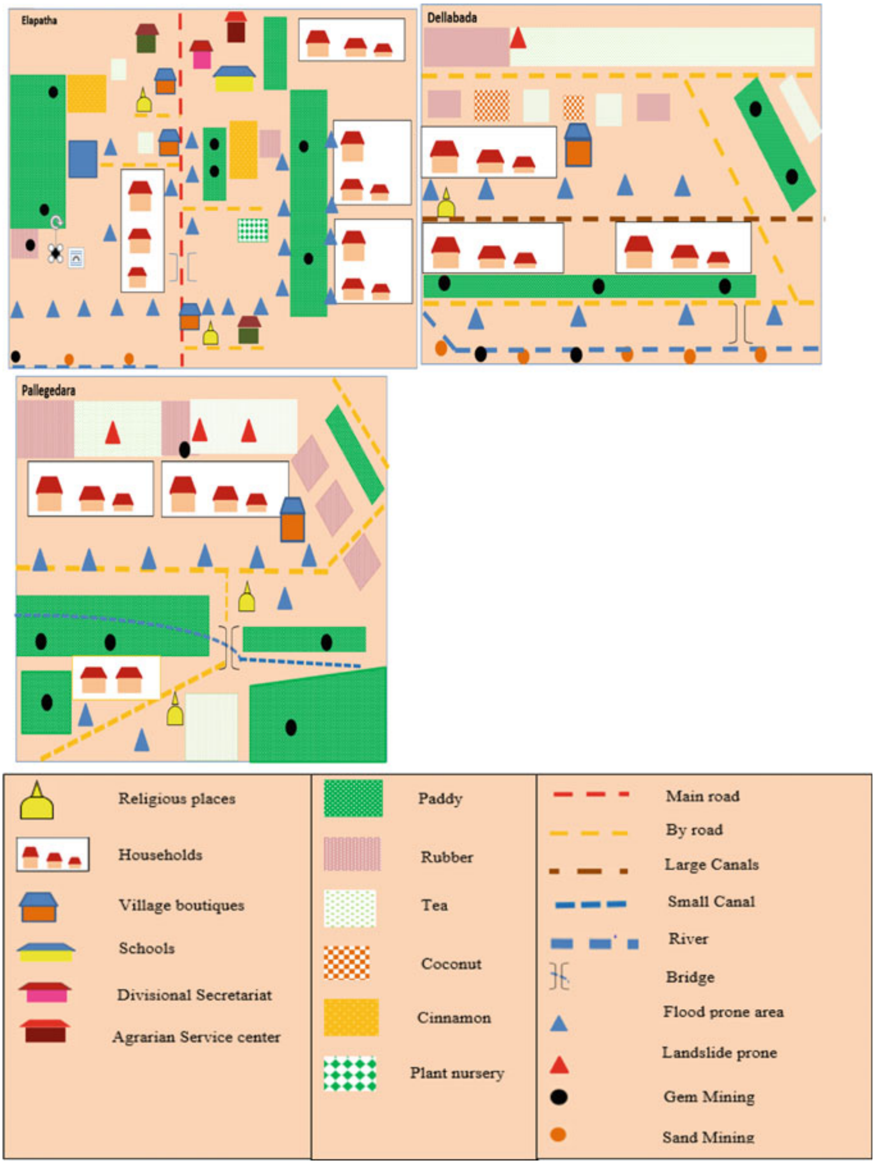

Fig. 4 Social mapping

4.2 *Impact on the Financial Assets*

One major economic consequences of natural disasters are the loss of income due to the impact caused on the agricultural production and also loss of employment. Floods make land unsuitable for agricultural production until waters recede. Paddy tea and rubber cultivations are considered to be the major commercial crops grown within the area. The land use map highlighted the present situation where cultivated crops and few gem mines are depicted in Fig. 5. As the staple food, paddy production is playing a key role in the agricultural sector (Basnayake et al., 2017). The average paddy yield of the study area for the year was around 30–40 bushels/acre in the *Yala* season and 60 bushels/acre in the *Maha* season. The drastic reduction of the yield in the *Yala* season was due to the floods encountered within the period. However, the farmers were also inquired whether mining activities had reduced the production of the crops during the recent 10 years. About 62–68% of the farmers perceived that the paddy

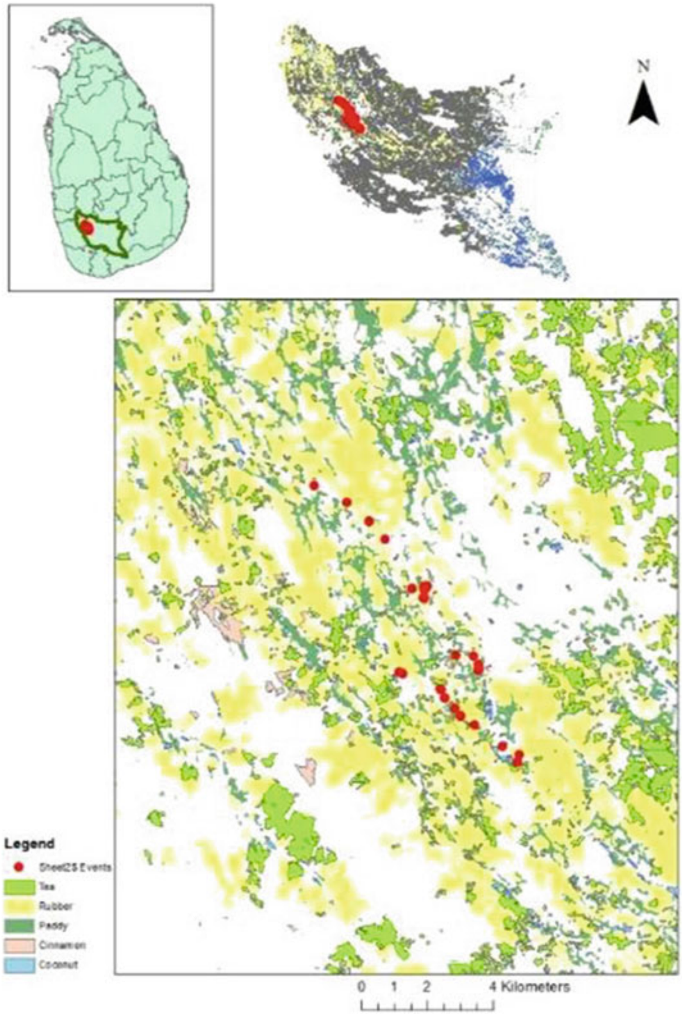

Fig. 5 Land use map of the study area

and the tea yield had respectively reduced during the recent 10 years due to negative implications of gem and sand mining. Frequent floods and its negative consequences had made agriculture less attractive to the farmers. This causes loss of crop harvest and poor-quality product and finally fetches low prices. Majority of the farmers are paddy farmers, they face difficulties in milling their rice during the time of disasters and selling their produce. This had impacted their income during the time of disasters. Disasters negatively affected on work time, loss of working days and sometime loss of occupation making households more vulnerable. Household expenses are managed through savings, pawning jewelry, informal borrowings. Further, farmers are force to utilize their saving and also fall into the trap of micro credit. Focus group discussions revealed that 90% of the farmers are victims of microcredit and due to mismanagement of the money they are further pressed into the debts. This had pushed the farmers below the poverty line increasing their liabilities.

4.3 Impact on the Physical Assets

The physical assets include privately owned by households (such as dwellings, tools, livestock or farm infrastructure) or they may be public assets accessed by households, such as roads, irrigation reservoirs and major canals, or electricity networks. The social mapping done to study area illustrates the vulnerability of the physical assets to be damaged by the disasters (Fig. 4). The damage for the physical assets is summarized in Table 2. The cost incurred on the physical assets during the recent 2017 floods were estimated as one million LKR. Gem mining activities has caused cracking walls of houses and manmade structures. However, the cost incurred by the manmade disasters especially by mining has not been quantified.

4.4 Impact on the Human Assets

The population of Pallegedara, Dellabada, Elapatha that were affected due to the recent major floods as shown in Table 1. The natural disasters had made Agriculture less attractive and people moving away from farming. Results revealed that a paradigm shifts of the occupations in the area; males were moved from farming to mining and majority of the females were engaged in an income generating activity or employed rather than confining to household chores. However, the registered farmers out of the total population of the Pallegedara, Dellabada and Elapatha GN divisions counts as 4%, 15%, 15% respectively. In general, young generation has shown more interest in mining rather than agricultural practices due to the thirst of lucrative and quick earnings.

Table 2 Impact of disasters on livelihoods assets

Impact on social assets			
	Elapatha	Pallegedara	Dellabada
Population affected	471	1638	286
Households affected	111	286	65
Cost of maintenance of displaced person			
Cooked food	Rs. 1260 per family/week	Rs. 1260 per family/week	Rs. 1260 per family/week
Dry rations	Rs. 3000 worth dry ration hamper/family/week	Rs. 3000 worth dry ration hamper/family/week	Rs. 3000 worth dry ration hamper/family/week
Impact on children's education			
a. Children affected age above 5 years (directly)	58	363	45
b. No of school days missed	Average of 4 weeks/year		
Impact on economic assets			
a. Loss of employment (average man days lost	Average of 4 weeks/year		
b. Reduction of the paddy yield	30 bushels per acre in the Yala season is lost compared with Maha Season		
Impact on physical assets			
a. No of damaged houses	320	367	222
b. No of damaged roads (minor roads	4	3	5

Source Elapatha divisional secretariat

4.5 Impact on Natural Assets

The agricultural lands had severely affected by both natural and manmade disasters. Floods and landslides had caused the loss of top soil, loss of soil nutrient, soil compaction, soil erosion making agricultural land unproductive. The percentage of the barren paddy lands of Pallegedara, Dellabada, Elapatha are 7%, 20%, 26% out of the total paddy lands respectively. Apart from the disturbance to land both natural and manmade disasters had negatively impact on the quality of water. Flooding of water wells of the farmer family had severely impacted their access to potable water. Further, mining activities both gem and sand had impacted on declining the water table and shrinking the water level within the area. Further, the discharge of tailings, sediments, chemicals (e.g. acid from batteries) lands explosives, diesel, and rubbish disposed into hydrological environment and contaminate the water. Forest land is another important type of natural capital and may be privately, communally or state owned. Study revealed that extensive emergence of plantation and mining had also reduced the forest cover within the study location.

5 Barriers

Natural disasters are unavoidable and became regular annual events devastating physical and natural property. Human activities; gem and sand mining have aggravated the frequency of occurrence of disasters. Gem and sand mining made negative impact on small holder agriculture systems. Of the sample 37% of the farmers believed unsustainable gem/sand mining is common due to the influence of gem miners where 45% strongly agreed to the fact that the corruption of law enforcement agencies lead the unsustainable gem/sand mining. Further, 36% strongly agreed that minimum supervision on mining activities by officers facilitate the illegal operations. More than half (43% strongly agreed and 14% agreed) that the license holders usually neglect the license rules to acquire extra margins. Majority including 51% strongly agreeing on the fact that widespread small- and large-scale illegal mining has been one of the major precursors affecting the small holder agricultural system.

6 Conclusion

The study area is highly prone to both natural and man-made disasters. The most common natural disasters were floods and landslides. The man-made disasters included excessive artisanal and commercial gem mining and sand mining. Both natural or manmade disasters thus had made the farmers at a greater risk of falling into poverty. The aftermath of natural and manmade disasters conflicts with the local populations' agricultural livelihood activities. The social, human, financial, physical and natural assets were severely impacted by the disasters. Farmers were socially affected due to constant displacements and relocations, disruption of education of their children, health risks, psycho-social and protection issues. Disasters had also affected the human assets affecting the employment patterns of people and the emergent of unskilled labour. Loss of income due to low productivity in agriculture have resulted the farmers to move in micro credit and pawning of their jewelry, thereby impacting the financial assets of farmers. Both private and public physical assets were damaged and destroyed due to both natural and manmade disasters. Land and water which are two main natural assets were impacted by the disasters where water quality, land use quality and thus affecting the agricultural production. However, the study identified bureaucratic issues which act as brakes to minimize the detrimental manmade activities on agricultural system. Disaster risk mitigation strategies and joint action is needed to thwart the consequences of poverty and disaster.

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A Site Specific Study on Peacock and Human Conflict—A Case Study from Jayanthipura Grama Niladhari Division, Polonnaruwa—Sri Lanka

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Abstract Studying human wild animal conflict is one of the best evidences to show the changes of their population and the carrying capacity, which increases the conflict. Peacock (*Pavo Christatus*) is distributed mostly across low country dry zone in Sri Lanka. Peacocks were identified widely in jungles in past whereas now they become one of the prominent bird species in human dominated land uses. Therefore, the present study was carried out to find the dynamics of peacock population and the problems encountered due to their exposure to the anthropogenic environment. Field observations and a structured questionnaire survey were conducted in Jayanthipura Grama Niladhari Division of Polonnaruwa district in Sri Lanka. A total of 50 birds were enumerated during the observations in the period between 1500 and 1900 h. 30% out of the total informants suggested seasonal climate change and agricultural pattern as the root causes for the dynamics of peacock population in the area. More than 80% of peacocks get disappeared during Yala season where they again begin to appear in Maha season due to the assurance of food during cultivation season. 60% of them come to the village from September to March during North East Monsoon in search of food. Availability of food sources and the easy access to water are the two key factors for the arrival of peacocks to this area during the Maha cultivation season. The results of the research will help to come up with more practical and effective solutions, more stakeholder's participation in human—peacock conflict management.

Keywords Wild animal conflict · Food security · Seasonal climate change

1 Introduction

1.1 Overview

The Indian Peafowl (*Pavo Christatus)* which is also called by the name "Peacock" in Sri Lanka is identified as the "king of birds" due to its high physical attraction. It

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ranks high among the most beautiful animals in the world and also one of the most popular ornamental park birds in the world. Although there are two main varieties of peacocks in the world, Indian Peafowl is the commonly distributed species in the world (Rajeshkumar & Balasubramanian, 2012). Indian Peafowl or the generally termed Peacock is commonly inhabited in South Asian region of the world and Sri Lanka also becomes one of the biological hotspots for peacock breeding due to the availability of favorable climatic conditions (Lukanov, 2013).

The reproduction of peacocks depends mainly on the angle of showing off the feathers and on the colors available in their feathers. One significant feature is that peacocks lose their feathers during a certain period of time in the year but they again get their feathers appeared on the body during reproduction period (Kang, 2013). Months from December to May are identified as the reproductive period of peacocks. Normally the peacocks are identified as flocks of about 5–6 members. They build up their habitats under the bushes in the jungle and are used to live on giant branched trees (Lukanov, 2013).

When paying attention on the behavioral patterns of the peacocks, it is very significant to identify the symbolic nature of their feathers. The peacocks show off their colorful feathers mainly to threaten the other peacocks in the area and to attract peahens for sexual activities. Peacocks are identified as a sensitive group of birds who are very much keen even on a very tiny soft noise in their surroundings. Although they are much sensitive and quickly reacted for human observations and disturbances, the studies have revealed that their reactions in front of predators are bit slowly (Gadagkar, 2013).

The species is virtually an omnivorous and opportunistic feeder on a wide variety of insects, plants, seeds, tender shoot, amphibians, reptiles, and worms. They have been adapted to eat the leaves and parts of plants which are suitable for their heights (Gadagkar, 2013). The recent studies on peacock food behaviors have identified a rapid flow of peacocks towards the home gardens and man-made agricultural lands in search of food (Dakin & Montgomeri, 2009). As they have the ability of eating a wide variety of food being omnivorous, peacocks have the ability to get adjusted to be fed on food they found around home gardens. A rapid flow of peacock populations towards human settlements have caused mainly due to the settlement fragmentation and habitat loss caused with population increase and human encroachments. This has paved the way for the occurrence of human peacock conflict in most of the South East Asian countries including Sri Lanka.

1.2 Human Peacock Conflict in Sri Lanka

Although the peafowls are identified as a variety of jungle birds, recently a rapid flow of the species towards human settlements could be identified in most of the dry zone and wet zone areas of Sri Lanka (Kang, 2013). The previous peafowl related studies in Sri Lanka have revealed several instances where the peafowls had invaded the agricultural lands of people harming them in numerous ways. This bird species has also been identified as an enemy of the farmer as they harm the tender paddy bushes even before they are ripen enough to harvest (Santiapillai & Wijeyamohan, 2015).

Especially the dry zone of Sri Lanka has become a comfortable area for the peafowls to live as that area is almost self-sufficient with many paddy lands and Chena cultivation lands which provide them a diversity in food (Lukanov, 2013). Food security and the diversity of food sources available in home gardens and Chena lands have attracted many peafowls towards the human settlements causing many conflicts between man and wildlife. Dry zone of Sri Lanka is favorable for the serpent growth and is famous for snake bites as well (Gadagkar, 2013). But the area has depicted a sudden decrease in snakes in the zone when there are peacocks around as the callings of peacocks have the ability to make the snakes frightened and very often the snakes become a good feast for the peacocks. Anyhow the arrival of peacocks to the home gardens and cultivation lands has become a critical issue in dry zone of Sri Lanka and therefore this study has been conducted in Jayanthipura Grama Niladhari Division—Polonaruwa with following objectives.

2 Objectives of the Study

The objectives of the study are as follows.

- Update the land use and locate the peafowl habitats in the study area.
- Identify the behavior of peacock population in the study area
- Assess the causes and impacts on people by peacock population.

3 Study Area

Jayanthipura Grama Niladhari Division (GND) in Polonnaruwa District of North Central province has been selected for the study. The GND is bordered to Hathamuna from North, Thanmbala Wewa from south, Girithale from west and Nagapokuna from east.

The study area receives the rainfall from North East Monsoon from December to February and this area includes to the intermediate relief zone. As this area belongs to the dry zone of Sri Lanka the average temperature varies between 23 and 27 °C.

4 Methodology

The methodology of the study will be discussed under three sub topics namely; data collection, data analysis and information presentation. 4.1 Data collection.

This study depends mainly on both primary and secondary data sources. Primary data was collected through direct observations and through a questionnaire survey. Direct observations have been carried out in five selected sample places in Jayanthipura GND. The five sample places were selected in such a way that it represents the dynamics in land use of the area. The samples taken for direct observations included.

- A home garden
- A small woodland near the home garden
- A school land
- A public play ground
- A small paddy field closer to the home garden.

Field observations were carried out in the above selected places in 3 consecutive days per week and the study period was 2 months during North East Monsoon period. The observations were carried out between 1500 and 1900 h as it was identified as the productive time of peafowls.

In addition to field observations, a questionnaire survey was carried out among 20 randomly selected people including 4 from each sample place used for field observations. The questionnaire survey focused mainly on the identification of causes and impacts of peafowl invasions towards human settlements and agricultural lands. The sample of 20 informants were selected based on the field observations done in the pilot survey of the study.

Secondary data needed for the study were collected from the resource profile of year 2018 available in Hingurakgoda Divisional Secretariat office. And also the literature related to the past studies on this matter were obtained via internet and libraries.

4.1 Data Analysis

The analysis of data was accomplished with priority ranking analysis using Microsoft excel and SPSS statistical analysis tools interactively.

4.2 Information Presentation

Graphs, maps, charts and tables have been used in illustrating and presenting the results of the study.

5 Results and Discussion

5.1 *Identification of Habitats of Peafowls in the Area.*

The direct field observations carried out in the study area could identify 5 main locations with peafowl habitats in the area. The base map prepared for field activities were updated while doing the field observations. Figure 2 shows the updated base map with the relevant locations (Fig. 2).

The observations of the study could identify a dynamic nature in the distribution of peafowls in the selected sites. The results of the observations suggested that more than 60% of the identified peacocks had visited these sites between the periods of 9–12 am. And also the study identified home gardens as the most popular site which had nearly 38% of the identified peafowls during the study period. When comparing the percentages of peacocks identified in school land and playground area, with those of in paddy lands and home gardens, the cultivation lands including home gardens and paddy lands rank high (67%). The reason for having high concentrations of peafowls

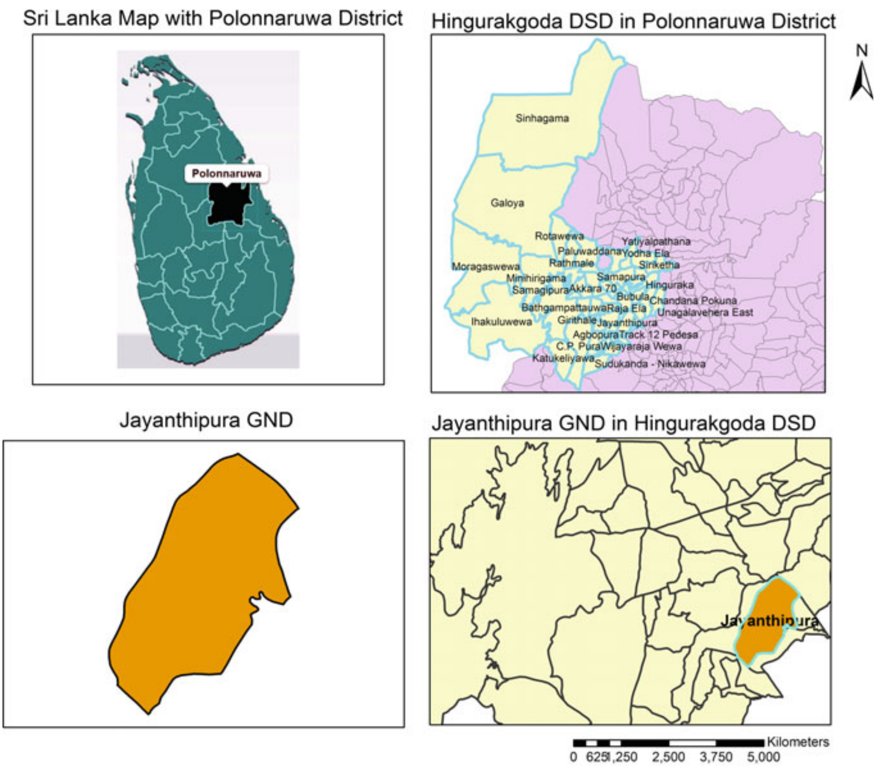


Fig. 1 Map of the study area. *Source* Prepared by author using Arc GIS 10.5

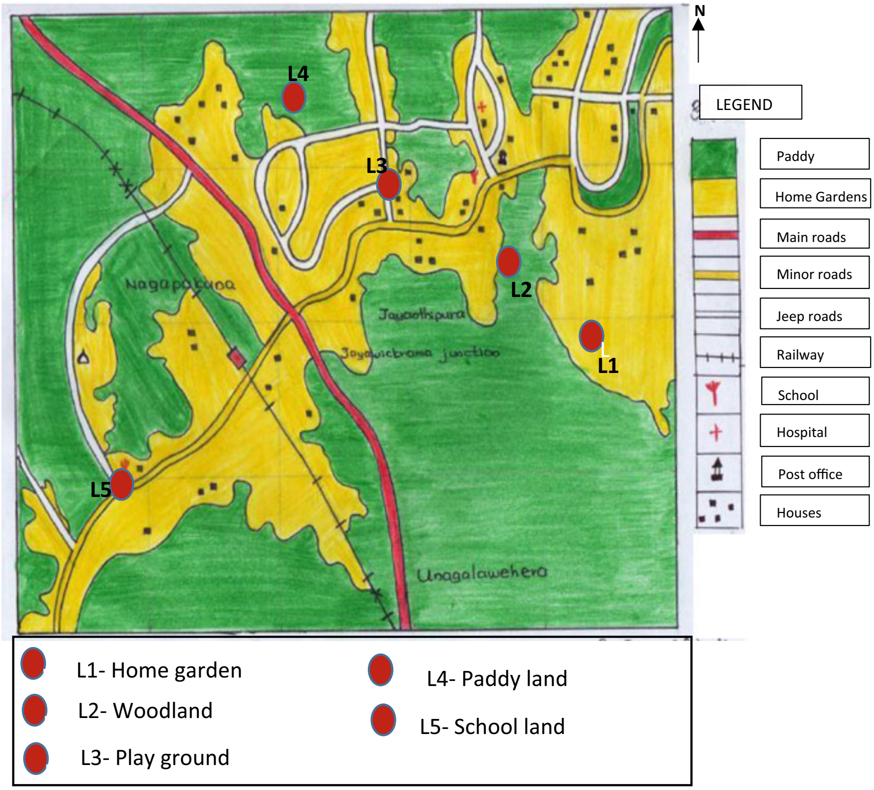


Fig. 2 Updated base map with the relevant observation locations. *Source* Field survey (2019)

in cultivated lands is the food security and the heterogeneity of food sources available in those areas (Fig. 3).

Comparatively a small number of peacocks could be identified in school land (9%) and in playground (5%) mainly due to the lack of food for their consumption. The peafowls are more used with the feeding habits woven around their jungle habitats and now it has been changed to a greater extent with their immense interaction with the human environments. Their adjustment to the human environment and for unusual food patterns were clearly depicted through their behavioral patterns observed at school land and at the playground.

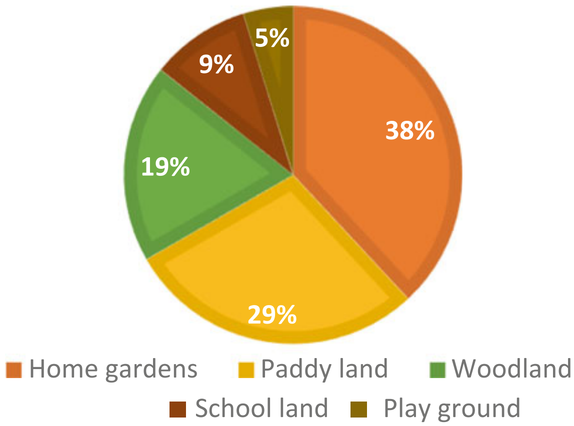


Fig. 3 Peafowl availability in selected locations. *Source* Field survey (2019)

5.2 Identification of Dynamics in Peafowl Concentrations in the Area

The results of the questionnaire survey and field observation will be discussed in this section. People of the area have observed a gradual decrease in the number of peafowls in the area during last 5–6 years. Five major reasons have been highlighted by the people for the decrease in peafowl individuals in the study area.

Figure 4 depicts five main reasons for the decrease of peafowl individuals in the area after the analysis of the data collected from questionnaire survey. Climatic changes are identified as the major reason for having low concentrations of peafowls in the study area. Peafowls being a very sensitive species of birds, have adapted to the dry zone high temperate climate in the region. However the lack of water in accessible water sources for them to drink and inability they have to find food with

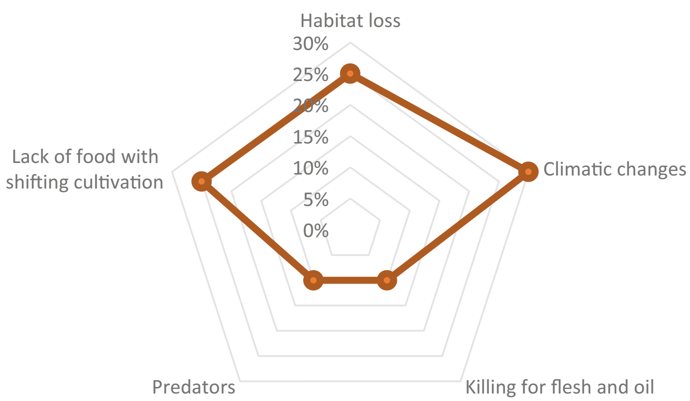


Fig. 4 Reasons for decreasing peafowl concentrations

the drought environments have led them to have dynamics in their concentrations in the area.

Habitat loss is identified as second major reason where the population pressure and human encroachment have become the dominating causes of habitat degradation. Especially the habitats which were associated with home gardens and paddy lands have been disappeared within past 5–6 years with the building up of new constructions for development activities. Peafowls are being killed by people for their flesh and oil. This has also become a reason for getting the peafowl concentration reduced as the predators also kill these birds for their food at the same time (Fig. 4).

Another significant factor that the study could reveal was the relationship between snake distribution and the peafowl concentration in the area. Dry zone of Sri Lanka provides home for many venomous snake species in Sri Lanka. Peafowls being omnivorous species of birds, snakes become of their favorite feasts. But the decrease of peafowls in the area has shown an increase in the snakes as there is no enough peafowl predators to kill the snakes for their food. Graph 3 shows the relationship between the spread of snakes with relation to the decrease of peafowls in the area within a period of one week (Fig. 5).

Figure 5 clearly suggests that there is a significant increase in the snakes when the peafowl population is decreased in the area. The man reason for this is the reduction of predators for the snakes in the area. 80% of the informants suggested that snake bites are higher due to this increase of snakes in the area when the peacock population is decreased with climate change and habitat fragmentation.

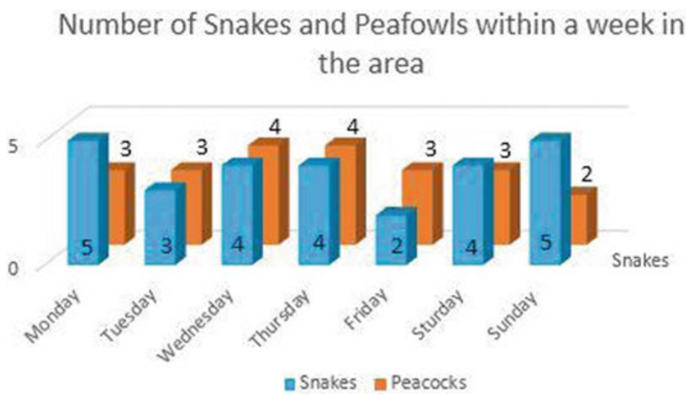


Fig. 5 Changes in Peafowl and snake distribution in the area. *Source* Field survey (2019)

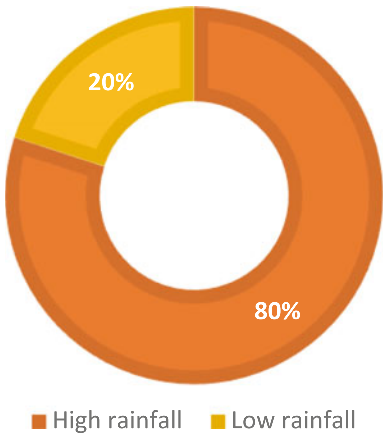
5.3 Influence of Seasonal Changes on Arrival of Peafowls to the Village

The study suggested rainfall as one of the major decisive factors that determine the arrival of peafowls to the village. The results revealed that nearly 80% of peafowls are coming to towards the village areas with the onset of rainfall. Especially in the dry zone, tanks and reservoirs become the major sources of water for both humans and animals. Therefore a significant increase of flow of peafowls towards the village areas can be marked out (Fig. 6).

With the start of rainfall, more than 90% of cultivated lands are being harvested by the farmers and the arrival of peafowls to the cultivated lands become a huge threat for the farmers. The conflict between human peacock starts from that point as both human and peacocks are competing for the limited amount of food and water resources available in the environment.

The study further identified a rapid flow of peafowls towards the village areas during Maha season. 60% of the informants suggested that most of the peafowls who had gone to the jungle due to lack of food in village areas with scarcity of water in Yala season are coming back to the area in Maha season in search of food and water. Maha is identified as the period which brings the North eastern monsoon to the area allowing most of the barren lands to get maximum harvests. Therefore it clearly suggested that peafowls come to village areas to get their food and water necessities fulfilled meanwhile it becomes a huge threat for the farmers to do their cultivation activities. Therefore the conflict between man and peafowls is emerged causing huge damages to both parties at the end.

Fig. 6 Influence of rainfall on arrival of peafowls to village. *Source* Field survey (2019)



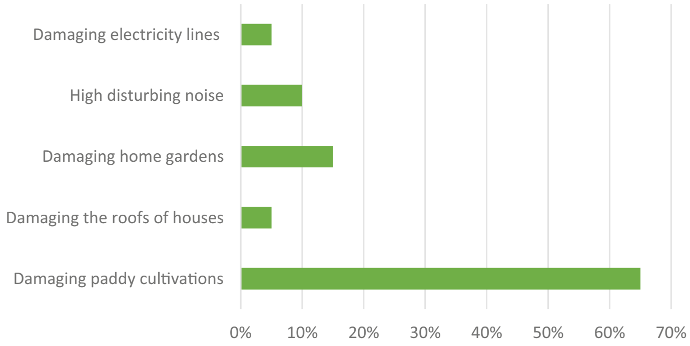


Fig. 7 Impacts of peafowls on human activities. *Source* Field survey (2019)

5.4 Impacts of Peafowls on Human Activities

The study further identified several negative impacts that have been caused on the daily lives of the people living in the area. As cultivation becomes the main livelihood of more than 85% of the people living in this area, the peacocks have become a huge threat for their cultivation activities. The study suggested damages caused to the crops especially for paddy cultivation as the major issue (65%) faced by the people in that area. Apart from that peafowls had damaged the tiled roofs available in the area through their sharp beaks (Fig. 7)

As the peacocks have come to agricultural lands in search of food and water, the damage caused to the grain crops and green leaves are identified as immense damages. As the peacocks have their habitats in very huge trees like Hora, Kaluwara Rubber during the night times, their excretory materials are put on to the crops below their habitats. Further, this issue has become worst mainly in home gardens where the peacocks have damaged the tiled roofs of the houses causing many harmful impacts on the lives of the people. These reasons have become the root causes of Human Peacock Conflict in this area. The availability of grain harvest from paddy cultivations, availability of a favorable climatic condition as well as food and water security in home garden settings have further given them a comfortable platform to live in this area.

Among the methods followed by the people in the affected areas to cope with this problem, few significant methods could be identified. More than 75% of the informants reported that there is a mythological belief to treat the peacocks in divine as the peacock is identified as the vehicle of God Skadha (God Katharagama). Therefore the killing of this bird species is rarely taken place but in some places where Chena cultivation is mostly practiced, illegal killings of these birds could be identified. Also the study could reveal that these people have made their own crop calendars by themselves avoiding the seasons which have more peacock populations to cultivate the crops with less attraction to the peacocks. Further these people avoid cultivating the plants which have an approachable height for the peacocks especially in their home gardens and cultivation plots. Majority of the informants suggested assurance of food insecurity for the peacocks in their home gardens and agricultural lands as the best strategy to get rid from these problematic situations taken place due to peacocks.

6 Conclusion and Suggestions

The study concludes that peafowls have become one of the dominating bird species in the cultivation lands ad home gardens of dry zone of Sri Lanka. This significant variation available in the environment has the ability to cage the entire eco system which is a combination of many biotic and abiotic components in the surrounding.

The study which finally focused on the human perspective on this human peafowl conflict further suggested that peacock once the most beautiful ad attractive bird in their lives have now become the worst enemy of the farmers as they harm the entire cultivation lands which are about to harvest. Although the study ad identified several reasons for the decrease of peafowl population in the area, the majority of the people in the area were willing to see a less number of peafowls due to the huge damages that they had experienced with their half damaged cultivation lands.

With the decrease of peafowl population due to the habitat fragmentation ad human encroachment, the snake population of the area seemed to increase gradually. People suggested that it is better to get their lives killed from a snake bite than suffering in in front of a cultivated land which has been damaged by the peafowls. As cultivation is the main livelihood of the people, the impacts caused from the peacocks have become really non tolerable for the people.

The study further suggests both man and animals to share this earth harmoniously as this place is made for all living creatures to exist cooperatively. Therefore this study would be a remarkable eye opener for most of the executives and authorities which are compiling and monitoring the rules and regulations for sustainable environmental management.

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Flood 'Survivors' or Flood 'Dependents'? A Sociological Reading of Flood 'Victims' in Urban Sri Lanka

H. Unnathi S. Samaraweera

Abstract Often, flood affected people are identified as 'flood victims' where such persistent portrayals not only limit their identity but also overlook their experience as 'flood survivors' during post disaster contexts. This study aims to examine the role of flood affected people in the post flood disaster context particularly during reactive/response, recovery and reconstruction stages. Using the purposive sampling method, fifty flood affected households in Kolonnawa were selected to conduct a household survey. Further, twenty-five in-depth interviews with flood affected people and two structured interviews with officials were conducted. Being a constantly vulnerable group living in a geographically flood prone area, these flood affected people are frequently identified as flood victims. Though the research findings suggest that they have later transformed into flood survivors during the post flood disaster context, their continuous identification and uncritical representation as flood victims have positioned them to hold on to their identity more as victims rather than survivors. Subsequently, the continuous flow of material and social assistance received from outside agencies including the government, international non-governmental organizations and non-affected voluntary support groups in the long-term post disaster context has encouraged them to be flood dependents as opposed to survivors. This chapter argues how the overwhelming material and social dependency of flood affected people prompts them to hold on to their flood dependent role circumscribing their autonomous engagement in effective post-disaster rebuilding and future mitigation.

Keywords Flood victims · Flood survivors · Flood dependency · Sri Lanka

1 Introduction

Flooding has been a recurrent issue in Sri Lanka, not only damaging the built-environment but also causing casualties. Four river basins, the Kelani, Kalu, Gin,

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and Atthanagalu, dominate the map of flood inundation drawn by the Department of Irrigation. Riverine flooding as a flash-flood mainly occurs due to unplanned urbanization, the establishment of settlements in flood-prone areas, infrastructure development neglecting potential flood risk and inadequate maintenance of the stormwater drainage system. The rapidly changing cultural, social, environmental, economic, institutional and political factors highly influence the characterization of the post-disaster reconstruction process (Oliver-Smith, 2009). Due to the complexity of the reconstruction process authorities have a lesser degree of control than usual which provides space for local people to also control the reconstruction phase (Oliver-Smith, 2009). In this context, "understanding post-disaster recovery is vital not only for survivors, relief organizations, and governments but also for social scientists" (Aldrich, 2012, p. 16). Therefore, this research mainly investigates narratives of flood affected people primarily considering the impact it had on them during the reactive/response, recovery and reconstruction stages in the post flood disaster context.

According to statistics, the Sri Lankan Treasury has approved an amount of US$ 2,690,580 for disaster assistance in year 2016 within which US$ 2,464,571 has been allocated for flood assistance alone (Disaster Management Centre (DMC), 2016c). In addition, Sri Lanka has received a total disaster assistance amounting to US$ 1,007,442 including the assistance for flood responses worth US$ 21,717 from the external sources such as Oxfam, UNDP, ADPC, CSE, Red Cross, National Disaster Management Council, UNHABITAT etc. (DMC, 2016c). This proves how large sums are allocated and spent from the national budget by the Sri Lankan government annually in addition to the flow of relief assistance from external aid agencies during a disaster.

One of the major flood incidents in the recent past occurred in 2016 in Sri Lanka, from the 19 to the 25 May 2016, hitting across the country and affecting over 403,000 people in 22 districts (DMC, 2016b). According to statistics by the DMC (2016a), Kolonnawa in Colombo district was the most flood affected divisional secretariat reporting the highest number of victims from the Colombo district. In Kolonnawa divisional secretariat, 18,756 families including 94,151 people were affected and one death was reported by the 20 May 2016 (DMC, 2016a). Though the narratives of flood affected communities are pivotal to understand the post-disaster contexts including the reactive/response, recovery and reconstruction stages, they remain often neglected while developing disaster risk reduction programmes in Sri Lanka. Being constantly prone to floods and vulnerable by the geographical location itself, certain neighbourhood areas on the banks of the Kelani river, Sedawaththa in Kolonnawa, Colombo face a number of risks as a community. People who live in by Kelani river in Sedawaththa in Kolonnawa Divisional Secretariat have become a vulnerable community not only because of their geographical location itself but also due to their socio-economic background. Further, this community has been continuously affected by small-scale to large-scale flash floods every year during the rainy seasons. Despite the recurrent nature of flooding, the narratives of these flood affected people during their post disaster context often remain inadequately examined. Therefore, this research study attempts to fill this gap by investigating the narratives of flood affected people who live in Kelani riverside, Sedawaththa in Kolonnawa, Sri Lanka.

The research problem investigates socio-economic responses of flood affected people on the banks of the Kelani River, Sedawaththa during a post-disaster context. Using the purposive sampling method, fifty flood affected households in Sedawaththa *Grama Niladhari*[1] Division in Kolonnawa Divisional Secretariat were selected to conduct a household survey. Further, twenty-five in-depth interviews with flood affected people and two structured interviews with officials were conducted. Based on the research findings this chapter specifically examines how flood affected people, being a vulnerable group understand themselves and are presented by external agencies. They become flood victims during the reactive/response stage, who transform themselves into flood survivors and then subsequently become flood dependents during recovery and reconstruction stages with the continuous flow of financial and material support provided by external entities including the government.

2 'Flood Affected People' Becoming 'Flood Victims'

Since the participants of the research lived in a flood prone area, they have experienced and are familiar with small-scale flood hazards. Therefore, the people with better economic situations have learnt to hire a vehicle and in 2016 they left their houses before flood entered their neighbourhood, mostly upon receiving a flood warning. Only 6% of households reported they left their houses carrying their valuables in a vehicle. On the contrary, those who have less economic stability have left their most valuable equipment in an elevated place within their houses or in the neighbourhood and left for temporary settlements carrying other limited valuables in bags. The majority or to be precise 62% of households were in this position. These reactive phase actions clearly relate to class element as 62% households who directly went to the temporary shelters were from the lower middle class and working class.

In addition, class and social status highlight the variation in availability of social support systems within their social networks. 6% of households who left with their belongings in a vehicle and 22% of households who stayed in a relative's or a friend's place reported having received social support from their close social networks compared to the 62% of households who directly went to the temporary shelters without having such close social support networks. Similarly, studying evacuation decisions of flood affected people in December 2014 in Malaysia, Soon et al. (2018) argue that people with more social and community support were more likely to evacuate efficiently compared to those who lack such support. This study also suggests that available social networks of flood victims influence their decisions on evacuating

[1] *Grama Niladhari* Division is a sub-unit of a Divisional Secretariat and it is under the purview of Home Affairs Division, Ministry of Home Affairs. The size and the population of each *Grama Niladhari* Division vary. There is a public officer appointed by the central government titled as the '*Grama Niladhari'* who is responsible for carrying out administrative duties and responsibilities in each *Grama Niladhari* Division.

whether to a temporary shelter or a known person's house which is more familiar to them.

The class dimension has played a major role during the reactive/response phase of flood affected people. Most of the flood affected males were daily labourers whose income source is largely derived from the informal sector. Largely, their wives were either house wives, domestic servants on a daily income basis or temporary cleaning staff who were again working in the informal sector. When they faced flood hazard not only were they financially ill-equipped to deal with such hazards, but they also suffered with temporary unemployment during the reactive/response phase and early recovery stage until returning to their households and settling back in the post flood disaster context. It has been proven through various disaster studies that upper-class disaster affected people were better prepared to face disasters compared to those from lower class unskilled employments (Siromony, 2006).

When a situation is out of control for individuals due to unavoidable external factors such incidents are considered to lead that individual to be a victim (Hove, 2016). Furthermore, according to Bar-Tal et al. (2009) individuals define themselves as victims when they are unable or lack agency to stop the harmful incident, believe they are harmed, are suffering from the incident, think they are not responsible for the harmful act they face, ethically right, and reasonably expect to receive sympathy. Therefore, flood affected people in Sedawaththa can be identified as flood victims who have experienced an unexpected flood magnitude and have become helpless and powerless financially, socially and politically. In addition, the identity of a disaster victim often depends on history and culture (Clancey, 2016). As depicted in this research, the low income financial and social backgrounds, non-availability of well-resourced close social support network systems and weak socio-cultural backgrounds further contribute to identifying them as flood victims during such catastrophic events.

As illustrated through their narratives, those who went to temporary shelters lacked clean drinking water, dry or cooked food, proper lavatory facilities, clothing, medicine, sanitary napkins and this further contributed to their social identity as 'flood victims'. In addition, compared to males, females faced more issues without proper lavatory facilities, security, sanitation, health and safety. Since all flood affected people had to sleep in open halls without gender separation, the security and safety of their young children were serious concerns for the affected parents. Since the women and men encountered different types of risks and vulnerabilities it is proven that relief assistance should also address the gender-based needs of the affected people (Byrne & Baden, 1995). The research findings suggest though flood affected people have different narratives on socio-economic impact and response during and post flood disaster contexts, a common identity as flood victims has been formed among low income flood affected people, in terms of leaving their houses, staying in temporary places, temporary unemployment leading to permanent unemployment, loss of livelihoods, loss of materials, coming back to damaged houses, feelings of fear, insecurity, loss and brokenness etc.

3 'Flood Victims' or 'Flood Survivors'? Rethinking Identities of Flood Affected People

Everybody in the sample reported that their houses required cleaning and renovation after the disaster. Two thirds of the survey sample reported minimum damage to houses while one third reported heavy damages. However, after the flood hazard, during the recovery phase, the people who had a better economic background recovered easily compared to those who did not have such economic savings with them. It has become evident through numerous disaster studies that wealthier upper-class disaster affected people who had access to better resources and information recovered and stabilized rapidly after San Francisco earthquake on 18th April 1906 (Bowden et al., 1977); post Kobe earthquake (Sawada & Shimizutani, 2008; and after Katrina (Underhill, 2009). Therefore, it can be argued that social class and status influence the process of the reactive, recovery and reconstruction stages of disaster as was the case in Sedawaththa flooding. The following two quotes further support this argument:

> "When we heard that flood is about to reach, my brother in-law came in his van. We hired a small lorry and left the house immediately. We took almost every valuable thing with us. Luckily, we did it. Because when we came back to check on the house after the flood, the house was muddy and fully ruined. So, my husband and I came with some male relatives and cleaned the house before returning to the house. The flood line is still visible in our house if you check it properly". (Meena, In-depth interview: 22/07/2016)

> "We did not have any financial background. When the army soldiers came to support the cleaning and rehabilitation of affected households, we felt very grateful". (Geetha, In-depth interview: 23/07/2016)

Those who stayed in temporary shelters received support from army soldiers and volunteers to clean their houses. However, it became evident that the people who had a more secure financial background and relatives' support have recovered quicker than those who did not have such social support.

In addition, 56% of households reported temporary unemployment during floods as well as during early recovery stages. The financial background of flood affected people and the type of employment were clear determining factors directly affecting the recovery and rehabilitation process of flood affected people. Further, 32% of the whole sample reported actual loss of employment during the recovery and reconstruction stages. As indicated in the following quotes, the majority of the flood affected people have lost their informal sector work due to the flood hazard which made them more vulnerable not only financially but also socially and psychologically:

> "I worked as a domestic servant in a house in the city centre on a daily income basis. When we got the news on flooding in upper neighbourhood we quickly moved to the temporary shelter in school where we usually go to during a flood. We stayed there for three weeks. So, I could not go to work. After the floods, we came back home to start on cleaning our house with the support of army soldiers and other volunteers. Then I went to work as we did not have any money to buy food. When I went there, madam told that now they have hired a new domestic servant as I did not show up for a month. So, I am unemployed and I have two children to feed". (Sumana, In-depth interview: 23/07/2016)

> "I do not go to work as we have an infant. Also, we have another son who is 4 years old. My husband worked as a labourer in a construction site. He could not go to work during the flood as he was afraid to leave us alone in the temporary shelter. Then he lost his job. Now he is going everywhere looking for work". (Rekha, In-depth interview: 22/07/2016)

The term 'survivor' simply stands for a person who remains alive after some incident in which others have died and also for a person who copes positively with the difficulties after some incident or in their life generally. Benwell and Stokoe (2006) argue the context, including place or environment, of identity construction is a significant aspect to consider when analyzing identity formations. Due to the lack of literature directly focused on flood victim, flood survivor and flood dependent identity, in this chapter the identity of flood affected people is conceptualized specifically in relation to the flood context. Following the argument that these flood affected people become flood victims due to their vulnerability largely associated with their reactive/response, recovery and reconstruction stages, what the researcher here attempts to unfold is the invisible aspect of them becoming flood survivors. Even though their identity reflects their victimization, the unexplored element is how they attempted to resume their lives as flood survivors as opposed to victims. Flood affected victims returned to their damaged households immediately after the flood, cleaned their houses and attempted to restart their lives, utilizing available strengths and capacities to adapt and to settle back while facing various economic, health, social and political difficulties. This study therefore contends that the flood affected people coped positively in the post flood disaster context as 'flood survivors'. Moving to the central argument of this chapter, the next section considers how flood affected people who gradually grew from flood victims to flood survivors have later transformed into flood dependents instead of emerging as resilient flood survivors.

4 Flood Victims Versus Flood Survivors Versus Flood Dependents: Transformation as Flood Dependents

As depicted in Diagram 1, when considering flood affected people as flood victims the majority of them have left their households only with carriable things such as mobile phones, a few clothes, jewelry and some documents. This reflected their financial, social and psychological suffering. However, during their stay in the temporary shelters, they have received fundamental needs such as food, drinking water, some clothes and medicine. Further, all narratives represented the sense of powerlessness, worthlessness, low-confidence and hopelessness due to the flood hazard which made them victims of the flood in that early phase. Similarly, Hove (2016) outlines the characteristics establishing a victim such as powerlessness, self-worthlessness, low self-respect, hopelessness, guilt, loss of faith and a tendency to hold themselves responsible for the situation. According to Bar-Tal et al. (2009) those who cannot merely stop the incident by themselves and are unable to make themselves accountable for the event are identified as victims who further require empathy for the harm

Victim →	Survivor →	Dependent
• Leaving houses • Staying in temporary places • Temporary unemployment leading to permanent unemployment • Loss of livelihoods • Loss of materials • Coming back to damaged houses • Feelings of fear, insecurity, loss and brokenness • Sense of powerlessness, worthlessness, low- confidence and hopelessness	• Cleaning & returning to their households immediately after the flood • Attempting to settle back • Using strengths and capacities during reconstruction and recovery stages • The ability to cope with the situation • Resuming the lives in the post flood disaster context	• Obsessed with the material needs • Preoccupied with receiving every material benefit from outside • Waiting for more aid even after three months and six months of the disaster • The lack of individual confidence, courage and an attempt to recover and reconstruct as a household and/or as an affected community. • Do not consider long-term recovery plans and future mitigation plans among themselves as a community

(Fieldwork data, 2016)

Diagram 1 Flood victims versus flood survivors versus flood dependents

they face. Since, a flood hazard is beyond the control of the flood affected people to a certain extent, it is apt to conceptualize them as flood victims in this context.

However, after experiencing such a catastrophe, the flood victims have returned to their households within two weeks to one month after the flood. With the help of government rescue teams including the army and navy soldiers and non-affected volunteer support groups, they have cleaned their houses immediately after the flood and have tried to settle back. At this point, their identity as 'flood victims' transforms into 'flood survivors'. The researcher refers to them as survivors due to the strengths and capacities they have shown in relation to settling back in their damaged households again specifically highlighting the transformation they have shown from the first interview during the reactive/response phase to the second interview during the recovery phase. This transformation from flood victims to flood survivors represents their ability to cope with the situation and resume their lives in the post flood disaster context.

At this point, it is important to note how a flood dependent is defined in this chapter and why it argues that flood affected people have eventually become flood dependent. The dependency mentality is simply defined as an individual or a group who look for others to provide more or less everything to fulfil their financial, material, social and psychological needs as they believe in their inability to fulfil their needs including their lack of self-confidence (Lacobută & Mursa, 2018). In addition, "dependency is any chronic behaviour affecting a person or society so as to force it perpetually to succumb to depending on someone or society to address his, her or its needs and sometimes problems in order to develop" (Mhango, 2017, p. 01). However, specifically focusing on flood affected people in the post disaster context this chapter defines a dependency mentality as a state where people who are affected by the flood hazard continuously expect to fulfil their financial, material, social and psychological needs through other non-affected parties including the government without attempting to rehabilitate by using their own social capital available to them.

During the recovery and reconstruction process it was evident that flood survivors looked for all possible financial and material support provided by non-affected communities, non-governmental organizations, the government and other international donors. The material support such as clothing, dry food, kitchen equipment, roofing sheets, cement, sand, other equipment and goods required for the reconstruction of houses made the recipients preoccupied with their material needs without paying much attention to developing long-term recovery plans and future mitigation plans among themselves. The following quotes evidently prove the same:

> "Now we do not have any income. The government should take the lead and provide us more assistance at least for food and our basic needs. We cannot rebuild our houses without financial support from outside". (Rekha, In-depth interview: 26/10/2016)

> "We hope somebody will come and distribute more aid. Just after the flood there were a number of donors. Now nobody cares for us. We need any kind of help such as financial, clothing, food and medicine from anybody at the moment". (Rita, In-depth interview: 28/12/2016)

According to Dynes' (1998) categorization of dependent communities during disasters, this type of dependency can be categorized as 'client dependent' where outside agencies including the government, non-governmental organizations, international donors and non-affected communities come forward and provide different assistance which those agencies can justify in their capacity as requirements of the affected community. This kind of continuous assistance determined by the agencies makes the affected community passive receivers and dependents as was the case in Sedawaththa.

All households reported receiving dry food during the recovery process from different donors except for 6% households who had still not returned back as long as two months after the disaster. The members of 62% households who stayed in a temporary shelter from the beginning of the flood hazard reported receiving bulk dry food packets and tins which they brought to their houses upon return. Since a majority of them had lost their employment, rather than looking for a possible new employment, most of the affected people were reported as awaiting more aid. Since the researcher has visited the field periodically; one month, three months and six months after the disaster, it was observed and evident from the in-depth interviews, that the majority of males in the affected households were still unemployed. The interview information revealed that due to the hazard they had faced, they expected that material and financial support should be extended by the responsible authorities whereas the researcher observed a lack of individual confidence, courage and an attempt to recover and reconstruct as a household and as an affected community.

However, the compensation of 25,000 Sri Lankan rupees promised by the government per household later decreased to 10,000 Sri Lankan rupees. Even this decreased amount had not been received by 84% of households in the sample six months after the flood disaster. Only16% of households reported they went to the divisional secretariat with the required letters from the *Grama Niladhari* and subsequently received the money. The survivors organized a protest informing higher authorities that they had not received the money. This event was given high media attention. An interview with a key participant of the protest explained how important it was for flood survivors to get that money to recover their households and bounce forward in their lives. Similarly, the non-receivers of the compensation also explained they require that money to recover from the flood hazard. As narratives of the flood affected people revealed, a majority of those non-receivers have not attempted to find employment even three months after the hazard and were waiting for the government compensation. They tried highlighting the fact that they had lost their employment and expect more aid and support from all possible sources including the government. This notion of waiting for more aid and overwhelming material dependency upon any goods distributed as aid prove the fact that the 'flood victim' identity has eventually transformed into 'flood dependent' as opposed to 'flood survivor'.

When the survivors of the most roof-damaged households received asbestos sheets to repair their rooves, others who did not have their rooves damaged also went and complained they needed it. On the contrary, when a water rehabilitation programme and a garbage collection programme were carried out in the affected area, the support and participation of the flood affected community was at a minimum. The interviews with the flood affected community members revealed that they expected the supportive groups to visit and do that work for them. The affected households have received informal information that most required kitchen equipment will be provided by a politician in the area and a majority of the surveyed households had a list of equipment and goods they needed. This list was provided to anybody who they thought would come with aid. Ironically, the interviews revealed that they as affected victims of the disaster expect somebody to provide such equipment and goods as aid. Certain non-governmental organizations in the area have provided them with some of the goods and equipment needed for normal everyday life during the recovery and reconstruction stages. Further they have continued to ask them for more goods.

"An attitude and belief that a group cannot solve its own problems without outside help" is defined as "Dependency syndrome" or "Dependency mentality" (Harvey & Lind, 2005, p. 14). "A person is aid dependent when they cannot meet immediate basic needs in the absence of relief assistance" and "a community or a country is aid dependent when it cannot meet the immediate basic needs of its citizens in the absence of external relief assistance which is defined as an aid dependency" (Harvey & Lind, 2005, p. 15).

While discussing community disasters, Dynes (1998) argues that response-generated demands as opposed to agent-generated demands need to be addressed in a post-disaster context in order to achieve sustainable rehabilitation and recovery of the affected community. In line with Dynes' (1998) argument, this research reveals that external help attempts to address agent-based demands while lagging behind on response-generated demands. It is clear from the research findings that the response to flood hazard from the affected people was diverse, but led them to stand along as survivors. This sense of survival has however declined later with the extension of aid programmes based on agent-generated demands. In other words, this whole process of aid based on agent-generated demands was a contributing factor to the dependency mentality of certain low-income flood affected people which did not permit them to be flood resilient subjects.

Six months after the flood, the majority of flood affected narratives of low-income residents revealed a notion of financial and material dependency upon non-affected communities and other supporting agencies including the government. This overwhelming dependency mentality was not only limited to material and financial needs but also seen in relation to the development of mitigation and adaptation plans to avoid future floods. A majority of household information revealed that they expect the government to take steps for flood mitigation plans in the area. They believe that the sole responsibility of flood risk reduction is upon the government authorities. This shifting of responsibility to external entities has been part and parcel of dependency mentality of flood affected survivors who have become dependents due to the disaster.

5 Conclusion

This chapter examines the transformation of flood victims into flood survivors (during reactive/response phase) who eventually become flood dependents (during recovery and reconstruction stages) highlighting the overwhelming dependency mentality developed among some of the low-income flood affected people. It proves how constant identification and uncritical categorization of local people as a victimized vulnerable group has caused other non-affected voluntary support groups, non-governmental organizations, local and national government authorities to keep assisting low income flood affected people with goods and services. Such continuous material assistance has turned the low-income flood survivors into dependents rather than expediting the recovery process both individually and collectively. In conclusion, the overwhelming dependency mentality of flood survivors in terms of material and sometimes social support has made them hold on to their identity as vulnerable flood dependents as opposed to survivors in the medium term.

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Increase of Pluvial Flood in Borelesgamuwa Area with the Climate Change and Land Use Changes

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Abstract Flood associated with extreme rainfall is a common phenomenon in urban areas due to rapid urbanization. New constructions, paving of roads with tar and concrete pavements, filled marshy lands and garbage dumping are some of the reasons which trigger the flooding. Colombo metropolitan area and suburbs are rapidly developed during recent past with the change of global economy. More factories and industries were constructed since 1980s with the implementation of open economy policy in Sri Lanka. Parallel to this, garment manufacturing industries were established in Colombo and surrounding areas under the "Board of Investment (BOI)", causing the Migration of rural community to Colombo metropolitan area and suburbs in search of job opportunities. More buildings and housing complexes were established with this migration leading to rapid changes in land use. Due to all those changes Colombo and its suburbs faced frequent flooding. Boralesgamuwa area was one of the most flooded areas in the Colombo District and it belongs to Boralesgamuwa urban council. Government of Sri Lanka managed to mitigate flooding in the area of Boralasgamuwa, after launching a flood mitigation project. The present study is focused to identify the change of rainfall pattern with changes in climate and the land use in Boralesgamuwa area to identify reasons for flooding in the said area. Annual rainfall trend, Coefficient of Variance (CV), land use change, change of population and people's perception for the rapid change were analyzed to find the reasons for urban flooding. Results revealed that increase of rainfall intensity with the increasing annual rainfall trend is one of the reasons for the flood situation in Boralesgamuwa area. Comparison of Coefficient of Variance (Variability) for two periods 1980–1999 and 2000–2019 also indicates the increase of rainfall variability. Analysis of land use changes using ArcGIS indicated the city growth from 0.66 km^2 to 5.83 km^2 for the years 1975 and 2000 respectively. This has increased total impervious cover which will lead to pluvial floods.

Keywords Pluvial flood · Land use change · Climate change

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1 Introduction

1.1 Climate Change and Extreme Weather

Every year floods cause enormous damage all over the world (Jonkman, 2005). Floods caused by extreme rain events, or pluvial floods, are becoming a serious problem to many countries in the world. Extreme weather events, such as heavy rainfall, are likely to increase in frequency and intensity as a consequence of climate change (Brockhoff et al., 2019). Between 1998 and 2017, more than 526,000 people died worldwide and losses of US$ 3.47 trillion (in PPP) were incurred as a direct result of more than 11,500 extreme weather events (Global Climate Risk Index, 2019). Fourth Assessment Report (AR4), 2014, the Intergovernmental Panel on Climate Change (IPCC) has already predicted that risks associated with extreme events will continue to increase as the global mean temperature rises (Global warming). There is a direct influence of global warming on precipitation, as increased heating leads to greater evaporation. However, the water holding capacity of air increases by about 7% per 1 °C of warming, which leads to increased water vapor in the atmosphere giving rise to precipitation events with increased intensity. (Trenberth, 2011).

A changing climate leads to changes in the frequency, intensity, spatial extent, duration, and timing of weather and climate extremes, and can result in unprecedented extremes increasing exposure of people and economic assets has been the major cause of long-term increases in economic losses from climate related disasters (IPCC SREX, 2012).

1.2 Reasons for Pluvial Floods

People around the world are at risk of pluvial flooding causing huge economic losses with risk to human life in extreme cases. The most common source of flooding is when water levels in rivers rise and overtop their banks (‘fluvial’ flooding). Another familiar source of flooding along coasts results from a combination of high tides and stormy conditions. Less well known and understood are ‘pluvial’ (rain-related) floods (Houston et al., 2011). Pluvial flooding occurs when extremely heavy downpours saturate the urban drainage system and the excess water cannot be absorbed. Most of the pluvial flooding events are dangerous because they occur without prior warning. Climate change and land use changes due to urbanization are stress factors that increase the issue of pluvial flooding. Urban areas are particularly vulnerable to downpours due to their impermeable surfaces, such as paved roads, parking lots, and roof tops, that prevent rainwater from infiltrating and, as a consequence, generate increased surface-runoff thus increasing the risk of pluvial flooding in the urban areas (Zhou, 2014).

Extreme weather events (floods, droughts, etc.) would be more intense and more frequent with the climate change (IPCC, 2001), due mainly to variability of rainfall.

In addition, wet areas get wetter, and dry areas get drier and drier with the climate change. In regions with vulnerable places include small island states (Maldives and Sri Lanka), densely populated poor coastal population affected by increased flooding from sea and rivers.

Pluvial floods occur after short, intense downpours which cannot be evacuated quickly enough by the drainage system or infiltrated to the ground. Pluvial floods often occur with little warning in areas not prone to flooding—hence the ‘invisible hazard’ tag (Houston et al., 2011). Pluvial flooding occurs when rainfall that is usually converted into run-off, which can be evacuated by the drainage system, remains on impermeable surfaces and flows overland or into local depressions and topographic lows to create temporary ponds. Pluvial flooding only occurs when the rainfall rate exceeds the capacity of storm water drains to evacuate the water and the capacity of the ground to absorb water. This is usually associated with short-duration storms (of up to three hours) and with rainfalls >20–25 mm/hour. It can also occur following lower intensity rainfalls (~10 mm/hour) over longer periods, especially if the ground surface is impermeable by virtue of being developed. (Houston et al., 2011).

1.3 Land Use Changes in the Study Area

City dwellers of Colombo, the capital of Sri Lanka, and suburban areas are worried about their future, as they have to face a challenging situation due to uncertainty of the changes in rainfall pattern. As Colombo city and its suburbs are the most densely populated and city with most ongoing construction works at present in Sri Lanka, it can be considered as a disaster-prone area during heavy rainfall events. Several areas in and around the Colombo metropolis were flooded in many occasions due to heavy rains that persisted for many hours. Boralesgamuwa area is one of the main flood occurring areas in Colombo Metropolitan Region (CMR). Boralesgamuwa, situated in “Weras River” basin and the basin plays an important role to connect urban water flows from some parts of CMR to Bolgoda Lake. Bolgoda Lake is directly connected to the sea and therefore Weras River basin plays a vital role for flood protection in CMR (Fig. 1). Many years back, no construction was taken place over Boralesgamuwa area, but many land use changes occurred due to the migration of people to CMR during near past.

CMR and suburbs are rapidly developed during recent past with the change of global economy. More factories and industries were constructed after 1980s with the implementation of open economy in Sri Lanka. Parallel to this, garment industries were established in Colombo and surrounding areas under the “Board of Investment (BOI)”. Rural community migrated to CMR and suburbs seeking newly available job opportunities. More buildings and housing complexes were established with the migration of people and rapid land use changes have occurred. Boralesgamuwa in the Weras River basin is one of the non-developed area. It Many marshy lands, water logging areas, sanctuaries and green areas could be found over there. It was a natural basin connected to the Bolgoda Lake for flood protection in CMR. Bolgoda Lake

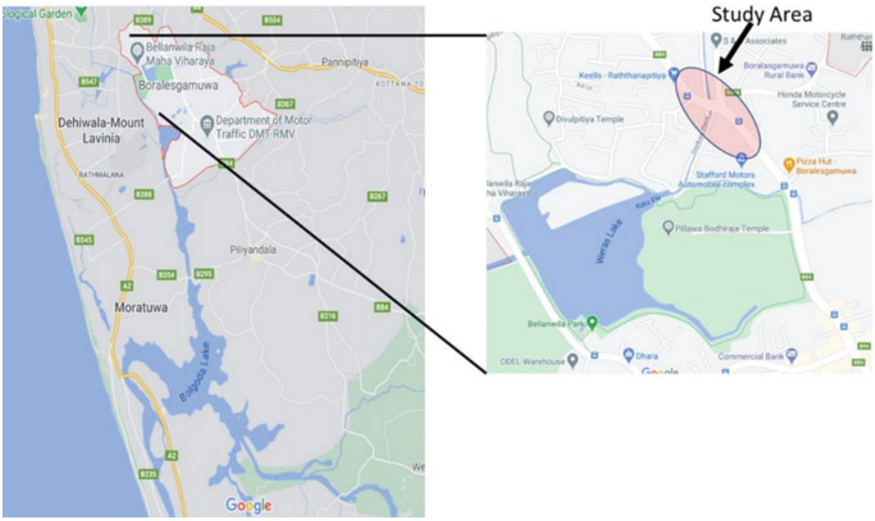


Fig. 1 Map indicating location of study

is directly connected to the Sea to drain water over the CMR and other areas in the vicinity. At present, Boralesgamuwa area is densely populated and according to the population data available at Boralesgamuwa Urban Council (UC), 1270 person were newly migrated or were born during the period 2009–2012. At present, the number of families and houses in the Boralesgamuwa Urban area is 14,711 and 14,781 respectively (Source: Boralesgamuwa Urban Council).

1.4 Pluvial Flood in Study Area

Flood events in Boralesgamuwa area since 1992 are listed in Table 1.

The present study is focused to identify the change of rainfall pattern with climate change and land use change in Boralesgamuwa area to identify reasons for flood in the said area. Annual rainfall trend, Coefficient of Variance (CV), land use change, change of population and people's perception for the rapid change were analyzed to find the reasons for urban flooding.

2 Data and Methodology

Primary data from the questionnaire survey, Satellite data from Landsat Image and Climate data for the period 1980–2015 were used for the analysis.

Table 1 Historical flood events and number of people affected at Boralesgamuwa

Reported flood date	Number of people affected	Daily rainfall (mm)	Reported flood date	Number of people affected	Daily rainfall (mm)
4-Jun-1992	–	365.5	4-May-2007	259	139.0
21-May-1993	225	148.2	17-Nov-2009	–	210.3
12-Oct-1999	–	236.3	17-May-2010	6377	177.1
25-Sep-2004	225	159.6	10-Nov-2010	5275	382.8
21-Nov-2005	2270	237.2	31-Oct-2012	–	142.6
18-Nov-2006	–	156.8	9-May-2015	140	21.4
			16-May-2016	63	192.0

(Data Source: Desinventar, News paper)

2.1 Questionnaire Survey

To find out the effectiveness of flood mitigation activities of this area, some data were collected from the primary sources. Primary data were collected for the field survey using Questionnaires, and Interviews. A fully structured interview was carried out with authorized personnel at Sri Lanka Land Reclamation and Development Corporation (SLLRDC) and Boralesgamuwa Urban Council (UC).

A questionnaire consisting of 21 questions was given to 50 randomly selected city dwellers (from age 18 years and above per house hold) of Boralesgamuwa UC area, in order to gather information on how long they have been experiencing flood, their experience of flood after the drainage redevelopment project, their perception of the; causes of the flood in the area, degree of damage, and the impact of flood. Houses were selected for the questionnaire according to the information given by the Grama–Niladari (Sri Lankan public official appointed by the central government to carry out administrative duties at village level) of different Grama–Niladari divisions.

2.2 Satellite Data (Landsat Images)

Land use change pattern is one of the important contributing factors contributing to the increased flood situation. Landsat images of 1975, 1992 and 2016 as well as administrative map of Boralesgamuwa UC area were used (Table 2). Data source was USGS (United States Geological Survey). ArcGIS technique was employed to analyze the images.

Perception of the people, as well as satellite data can be compared with the climate data analysis at the study area. As there was no rainfall observation station at the study location, closest two stations were considered for data analysis. Daily rainfall data was collected from the Department of Meteorology at Ratmalana and Colombo.

Table 2 Satellite remote sensing data format and sources

	Name	Path and Row/sheet No	Year	Fomat	Source	Scale/Resolution
1	Landsat	P152r55	1975	Digital	USGS	57 m
2	Landsat	P141r55	1992	Digital	USGS	28.5 m
3	Landsat	P141r55	2016	Digital	USGS	30 m
4	GN Division map of Sri Lanka		2000	Digital	Survey Dept of Sri Lanka	1:30,000

Information on flood occurrence was obtained from desinventar.lk web site and newspaper reports.

2.3 Climate Data

Identification of rainfall trends for the recent few decades is important to understand the trend and possibility of heavy rainfall events. Therefore, annual rainfall data from 1980 to 2019 were analyzed to identify annual trend and daily rainfall were analyzed to identify the change of daily extremes. Percentile based values were considered as the threshold values for heavy (90th percentile) and very heavy (95th percentile) one day rainfall. To understand the situation coefficient of variance (CV), which is a measure of relative dispersion, is used to compare the variation in series which differ in the magnitude of their averages.

2.4 Assessing Land Use Changes Over Time

ArcGIS (Arc Map 10.1) technique was employed to analyze the satellite images. Iso-cluster unsupervised classification was performed and reclassified into 4 classes as:

- Built up
- Vegetation
- Paddy/marsh area
- Water body.

In addition, Google map was used to identify the classes in 2016 image to maintain the accuracy. Area calculation was done in km^2. Annual % growth rate was calculated using Excel 2013 spread sheet.

3 Results

3.1 Analysis of Rainfall (Extremes)

Annual rainfall trends at Ratmalana and Colombo stations are shown in the Table 3. It indicates a significant increasing trend.

Percentile based analysis was conducted to find the extreme rainfall events at Colombo and Ratmalane. Period from 1961 to 1990 was considered as the base period and 90th and 95th percentile values for the same period was calculated using daily data. Percentages of number of days above the percentile value has calculated and represented as a percentage for the periods 1991–2000, 2001–2010 and 2011–2019 with respect to the number of days in the base period (Table 4). Analysis shows a significant increase of extreme rainfall events s during the recent period.

It is well understood that extreme cases (high and low) can be clearly explained from the standard deviation and Coefficient of Variation Therefore, CV was calculated and compared for the two periods 1980–1999 and 2000–2019 (Table 5). It shows the increase of variability for the recent period compared with the period 1980–1999. It indicated the increase of fluctuation of rainfall during the period 2000–2019.

Analysis of Rainfall clearly indicated (a) An annual increasing trend (b) Increase of Number of heavy rainfall events around Boralesgamuwa area. Therefore, highly intense rainfall will be one of the reasons for flood situation in Boralesgamuwa

Table 3 Rainfall trends at Colombo and Ratmalane

Station	Colombo	Ratmalane
Linear trend	$Y = 12.734x + 2051.2$ $R^2 = 0.121$, $p = 0.038$	$Y = 11.375x + 2204.9$ $R^2 = 0.088$, $p = 0.079$

Table 4 Percentage of heavy rainfall events in the decadal base at Colombo and Ratmalane

	Percentages of extremes					
	Above 90th Percentile (Heavy)			Above 95th Percentile (Heavy)		
Period	1980–1999	2000–2009	2010–2019	1980–1999	2000–2009	2010–2019
Colombo	37.4	36.5	38.3	17.9	18.3	19.3
Ratmalane	39.1	39.1	40.0	18.0	19.6	18.9

Table 5 Comparison of coefficient of variation at Colombo and Ratmalane (1980–1997 and 1998–2015)

	Coefficient of variance (CV %) 1980–1999	Coefficient of variance (CV %) 2000–2019
Colombo	14	17
Ratmalane	14	17

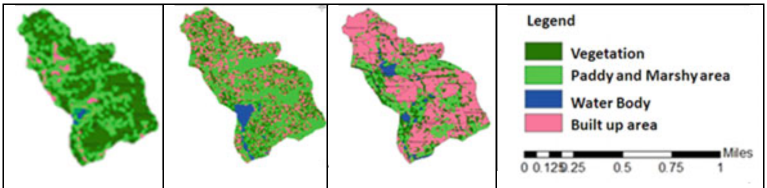
area. However, the situation is generally enhanced with the increase of population, improper management of natural drain system as well as land use change.

3.1.1 Results of Perception of the People Living in Boralesgamuwa Area in the Assessment of the Effectiveness of Flood Mitigation Activities of the Area

According to people's perception, 72% people perceive that floods will occur with the heavy and high intense rainfall events, while 65.3% said lack of drains is the main reason. However, blocked drains and defective drains an also major reasons for pluvial floods. 40.8% and 38.8% people think the reason for flood is the blocked and defective draining system. Even though Municipal councils have proper rules for new developments, buildings have been constructed over the waterways (44.9% of the answers) and uncontrolled property development (57.1% of the answers).

Urban flooding is mostly associated with land use changes. Lack of, or non-development and maintenance of the drainage systems, rapid development of buildings are some examples of these changes. In addition, dumping garbage, silting (no regular attention for clean canals), decrease of infiltration and increased building of houses with the urbanization are some problems for frequent flooding during recent past. Figure 2 and Table 6 shows the analysis of LandSat images for three different years as 1975, 1992 and 2016. It clearly indicates the change of land use as well as urbanization.

After classifying Landsat images of 1975, 1992, and 2016, an increase in urban area throughout the period can be clearly seen. From 1975 to 2016 total increase



Land Use Classification -1975	Land Use Classification -1992	Land Use Classification -2016	

Fig. 2 Landsat images—1975, 1992 and 2016 analysis of landsat images

Table 6 Land use change for1975, 1992 and 2016

	Vegetation (Km^2)	Paddy/Marsh (Km^2)	Water body (Km^2)	Built up area (Km^2)
1975	5.9	4.28	0.11	0.66
1992	2.36	4.62	0.4	3.57
2016	1.96	2.13	0.37	6.49

Table 7 Land use change, annual growth rate and % of change

	1975 (km^2)	2016 (km^2)	Change in Land cover (km^2)	Annual % growth rate	Change (%)
Built up area	0.66	6.49	5.83	1.0559	883.3
Vegetation	5.9	1.96	−3.94	−0.0259	−66.8
Water body	0.11	0.37	0.26	0.0293	236.4
Paddy/marsh	4.28	2.13	−2.15	−0.0165	−50.2
Total	10.95	10.95			

in urban area was 883.3% (Table 7). Marshy and vegetation cover was reduced since these areas were converted into built-up area. This had caused to increase the impermeable cover which has reduced the infiltration and storing the excess rainwater during heavy rains. This can be the reason for flooding in 1990s. There is no evidence of floods before 1992, and from the newspaper reports, in 4th June 1992, the study area had been heavily inundated with rainfall of 365.5 mm (Table 1). There were floods on 21 May 1993 with a daily rainfall of 148.2 mm affecting 225 people.

Although it is clear that the water body has increased in 2016 when compared with 1975, the reason behind was the construction of Weras Lake under the Weres River project by filling the marshy area with water. However, still the water body area in 1992 was greater than 2016. Reason for this reduction in water area in 1975 may be due to thew growth of invasive water plants like Salvinia covering the water.

According to a senior officer at SLLRDC interviewed, "Unauthorized constructions on drainages and lack of regular maintenance and cleaning are blamed for recurrent floods to the city. Uncontrolled landfill and flood plain encroachment have reduced water retention capacity of the area by 30%t during the last decade" and "The potential for boats to run on waterways have also been restricted by solid waste, floating debris and bottleneck in canals." He also stated the following about the Weres river project, "The project will dredge primary and secondary canals and lakes, upgrade drains systems within the urban council and build capacity in agencies about drainage management", and "Several artificial lakes were created with parks being built in these areas to collect excess water and this has proved to be successful as the flooding has decreased to great extent." By this we see that storm water flow was hindered by defective and blocked drains, whichhad been rectified by the Weres River Project. And also the project has increased the storm water storing capacity by artificial ponds. Responders of the questionnaire confirmed that flooding has been reduced by the project (Table 8, Question number 13, 94% said "no floods after drainage redevelopment project").

Nevertheless it is important to note here that the maximum rainfall after the Weras River project was 192 mm. According to Table 1 there had been urban flooding on 16th May 2016. Rainfall on that day was 192 mm.

Therefore, on a future date, only when an intense rainfall is received, we can answer whether the redevelopment project is sufficient to keep the area "flood free",

Table 8 Flooding frequency after Weres river project

Floods after Weras river project				
	Frequency	%	Valid %	Cumulative %
No	47	94.0	94.0	94.0
Yes	3	6.0	6.0	100.0

Table 9 Frequency of land filling

	Frequency	%	Valid %t	Cumulative %
Once	19	38.0	38.0	38.0
Twice	11	22.0	22.0	60.0
Thrice	3	6.0	6.0	66.0
None	17	34.0	34.0	100.0
Total	50	100.0	100.0	

because from this study we saw that built up area has increased significantly reducing the marshy and the vegetation areas.

According to the eye witnesses there were many land fillings during the past years. People's perception for that questions, 66% answered positive on land filling over the area (Table 9).

4 Conclusion and Recommendation

In this study it was shown that increase of rainfall intensity with the increasing annual rainfall trend is one of the main reasons for the flood situation in Boralesgamuwa area. Comparison of coefficient of variance (Variability) for two periods 1980–1999 and 2000–2019 also proved the increase of rainfall variability. In this area, city growth was from 0.66 km^2 to 5.83 km^2. This has increased the total impervious cover which will lead to pluvial floods.

Previous studies focused for flooding in CMR also found the similar results. Case study done by Dissanayake et al., (2017) on the 2016 flood in Sri Lanka, stated that the impact was severe at the Kolonnawa area (CMR), due to Illegal settlements constructed very closer to the flood plain areas which is protected from a bund created by Irrigation Department. By analyzing several flood events in CMR, Mohamed et al., (2017), concluded that annual rainfall has increased in Colombo Metropolitan Region. However, primary reasons for recent floods are increased surface runoff due to urbanization, diminishing flood retention areas, growing trend for rainfall intensity and inadequate conveyance capacities of canals, structures and outfalls.

According to the senior officer at Sri Lanka Land Reclamation Department (SLLRDC) this flood threat had been identified in this area and a massive project had been started based on Weres River which had addressed the following as preventive measures.

- Improvement of drainage efficiency
- Construction of flood protection structures
- Flood plain management
- Land use and development planning
- Planting trees (Green city).

Weras River project was a well-planned drainage re development project, but if legislative bodies are not strong and stop building along flood pathways these improved drainages will not be sufficient to cope up with intense rain situation like it experienced in 2010 which was 382 mm per day.

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A Conceptual Model for Community-Driven Ecosystem-Based Disaster Risk Reduction

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Abstract The land use pattern, disaster scenarios, and the impact on human needs are different over the past decades. In this context, mainstreaming disaster risk reduction in ecosystem-based approaches requires multi-sector and multi-stakeholder engagement with a better conceptual model, improved understanding of ecosystems, effective community engagement, and innovative use of spatial tools. In this study, a conceptual model for community-driven Ecosystem-based Disaster Risk Reduction (Eco-DRR) was conceived through the lessons from implementing a project in Sri Lanka. The model development process involved integrating global and local knowledge, engagements at national and sub-national levels and field applications of DRR concepts in Sri Lanka during 2018–2019 period. The qualitative information from secondary sources, key informant interviews, and social learning workshops were used in developing this model. The four key domains of the proposed conceptual model consists of (a) Development Planning; (b) Climate Change Adaptation; (c) Disaster Risk Reduction; and (d) Ecosystem Management. It includes four influencing factors at the community level: (a) Socio-Political Setting; (b) Risk Perception; (c) Institutional Arrangements and (d) Laws and Policies. Application of the model supports to four key result areas: (i) Increasing Human Security; (ii) Improving Sustainable Livelihoods; (iii) Strengthening Resilience; and (iv) Ensuring Environmental Sustainability. The model is presented as a 'Rubik's cube shape' model, since the domains, influencing factors and result areas have intra- and inter-relationships and overlaps.

Keywords Climate change · Development planning · Disaster risk · Disaster management · Ecosystem management · Risk management

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1 Introduction

Practice of Ecosystem-based Disaster Risk Reduction (Eco-DRR) is evident over the past decades to prevent and mitigate the impact of disasters such as droughts and floods (Gupta & Nair, 2012). The 2004 Indian Ocean tsunami brought an increased international attention on the role of coastal ecosystems as natural buffers against coastal hazards such as tsunami and cyclone, which in turn prompted wide ranging interest in ecosystem management approaches for DRR in general (Gupta & Nair, 2012). Several research findings have highlighted the effectiveness of ecosystem services and functions to reduce disaster risks, including coastal and urban flooding, tsunami, and storm surges (Kathiresan & Rajendran, 2005; Nel et al., 2014).

Many states prioritize and spend for disaster response and recovery over disaster risk reduction and preparedness (De Vet et al., 2019). Nevertheless, there have been a rapid evolution of concepts and frameworks in DRR over the past decade in the research literature. As a result, different types of DRR approaches in community based DRR, risk-sensitive development, and ecosystem-based DRR were adapted.

The ecosystems are highly vulnerable to natural and human activity-induced hazard impacts, which need urgent attention from all stakeholders for immediate actions for the conservation of ecosystems that are at high risk of further deterioration (Triyanti & Chu, 2016; UNISDR, 2015). Triyanti and Chu (2016) also highlighted that ecosystem-based approaches have not been specifically mentioned as "tools" for reducing disaster risks under 2030 Sustainable Development Goals (SDG). However, the role of ecosystem-based approaches are important in achieving many SDGs, such as SDG 2—Agro-ecosystems (Zero Hunger), SDG 6—Water related ecosystems (Clean Water and Sanitation), SDG 11—Urban ecosystems (Sustainable Cities and Communities), SDG 14—Marine and Coastal ecosystems (Life below water), and SDG 15—Mountain and forest ecosystems (Life on land) (CBD, 2018).

In general, the sustainable use and management of ecosystems to reduce disaster risks have been advocated from global to nation levels (UNISDR, 2015). The overall national DRR plans should include ecosystem-based disaster management policies, practices, and guidelines, which can then be operationalized to the sub-national and community levels. The field level operationalization of ecosystem-based DRR requires an understanding of the importance of physical ecosystem functions that can bring risk reduction benefits (Dhyani et al., 2018). Further, the ecosystem-based governance strategies across different spaces and levels need to be formulated within the community based set up to implement more effective DRR actions (Klein et al., 2019; Reid, 2016).

A number of sector specific development policies, institutions, and processes including new legislations and technical frameworks have been developed over the past years in Sri Lanka. The existing DRR related policies and framework have significant drawbacks, since there is lack of proper mechanisms for effective resource allocations within an integrated and holistic approach to development (Siriwardana et al., 2018). Although existing frameworks in Sri Lanka are mostly sector specific or thematically focused and implemented in isolation by the relevant institutions (Saja et al., 2020), they can be helpful to develop an inclusive and adaptable framework for ecosystem-based DRR. In this context, this chapter presents a conceptual model of a community-driven ecosystem-based DRR with inter-linkages of key domains, influencing factors and result areas from the lessons and reflections of implementing an Eco-DRR project in Sri Lanka.

2 Brief Overview of Eco-DRR Approaches and Frameworks

The literature in the fields of disaster and climate risks, resilience of communities, risk-sensitive development planning, sustainable development, and ecosystem-based adaptation have been progressing as integrated approaches in the context of post-2015 global agendas (CBD, 2018). Ecosystem-based DRR approaches have also been evolving over the past decade, and as a result many frameworks were developed (Faivre et al., 2018). For example, Cohen-Shacham et al. (2019) presented 11 ecosystem-based approaches into five key categories under the umbrella of nature based solutions (NbS) and categorised Eco-DRR under issue specific NbS. Many of these approaches were recognised as viable options in different contexts, yet, it is important to review the implementation of NbS through multiple case studies and evidence based practical application in multiple contexts to inform global and regional policies (Cohen-Shacham et al., 2019). Further, the research and empirical testing to understand cause-effect relationships of Eco-DRR in multiple scales (nested scales from local, regional to national scales) are still a challenge (Estrella et al., 2016). More prominence can be provided for ecosystem-based approaches in policy and practice to advance the achievement of sustainable development targets.

Nevertheless, a comprehensive scientific review was beyond the scope of this study, some of the literature that are relevant for ecosystem-based approaches were helpful in developing a conceptual model linking Climate Change Adaptation (CCA), DRR, Development planning and Ecosystem management, which is the aim of this study. Most of the existing literature discussed the inter-linkages between two or three domains such as, CCA and DRR (Lisa and Schipper, 2009; Brickmaan and Teichman, 2010), role of ecosystem services in CCA and DRR (Renaud et al., 2013; Munang et al., 2013; Sudmeier-Rieux et al., 2019), and disaster—development linkages (Fordham et al., 2009; Mochizuki et al., 2014). Further, limited number of models are available for establishing inter-linkages between development and ecosystem management, even though some environmental agencies such as IUCN have developed models linking multiple domains, yet need further improvement based on field level operationalization. Therefore, developing a model that can inter-link multiple domains, identifying influencing factors, and potential tools for operationalizing the model in practice can assist in addressing the key research gap.

3 Methods and Materials

The aim of this study was to develop a conceptual model to support more robust understanding of community-driven ecosystem-based DRR and contribute to the innovative literature in DRR approaches. This study adopted a multi-method data collection, which included, primarily the compilation of relevant literature, qualitative information gathered from secondary data sources, 22 Key Informant Interviews (KIIs), and eight social learning workshops with multiple stakeholders. In KIIs, district level key officials in the sectors of Disaster Management, Environment, Agriculture, Irrigation and Wildlife were involved. In each of the four project districts, two social learning workshops—one with government stakeholders and one with communities, were conducted. The data was collected by IUCN (International Union for Conservation of Nature) and Child Fund Eco-DRR project staff with the support of University Researchers during the last quarter of 2019. The data was analysed by generating concepts and themes using word clouds.

Four domains, related influencing factors and result areas used in the proposed model were initially selected based on existing studies such as Sudmeier-Rieux et al. (2019) and DEWGA (2008), which were then validated through a stakeholder consultation during a project implementation on Eco-DRR in Sri Lanka. The 'tools' and 'indicators' included in the model were drawn from the experience of field based project activities implemented by the key project stakeholders.

Related 'influencing factors' used in the model were prioritized by categorizing them based on the challenges encountered when advocating the implementation of 32 action plans developed by village youths participated for the YLEDRR project activities. The prioritised 'influencing factors' were validated during the quarterly steering committee meetings held in four project districts with key government officials.

Four result areas used in the model were prioritized in the social learning workshops with youth involved in the project, which consisted community visioning and risk reduction mapping exercises. A ranking exercise was conducted with the workshop participants to prioritise intended key outcomes of the micro projects they have developed. These outcomes were grouped together to identify the key result areas in the model. However, the tools identified in this study were restricted to the field-tested micro project interventions used in the 'Youth Led Ecosystem-based Disaster Risk Reduction' (YLEDRR project implemented by the Child Fund with the technical support of IUCN), which can be adapted or expanded based on field experience for future application. Key lessons from the YLEDRR project were incorporated to improve the conceptual ecosystem-based model and tools for DRR, which is currently being field tested in Sri Lanka.

The process of developing the Rubik's Cube Model for community-driven Eco-DRR also included the identification of roles and responsibilities of government ministries, secretariats, boards, departments and institutions in Sri Lanka. This process ensured the Sri Lankan government efforts to align national policies and strategies to facilitate the achievement of sustainable development goals. However, the tools discussed in the paper were prioritized based on the project experience, which need to be further expanded when more evidences and lessons become available.

4 A Community-Driven Ecosystem-Based DRR Conceptual Model

Ecosystem-based Disaster Risk Reduction (Eco-DRR) is the sustainable management, conservation and restoration of ecosystems to mitigate disaster risks, aims to accomplish sustainable and risk-sensitive development (Estrella & Saalismaa, 2013). Ecosystem-based DRR refers to decision-making activities that take into account biophysical necessities of ecosystems and future livelihood needs of people. The goal of DRR strategies based on the role of ecosystems is to enhance community resilience to prepare for, cope with, and recover from disaster situations (Sudmeier-Rieux & Ash, 2009). The conceptual model for community-driven ecosystem-based DRR is shown in Fig. 1.

This model is an intersect of four main domains; (a) Development Planning, (b) Climate Change Adaptation, (c) Disaster Risk Reduction and (d) Ecosystem Management with four main influencing factors; (1) Socio-Political Setting (2) Risk Perception of Communities, (3) Community Institutional Arrangements and (4) Laws and Policies which contributes for four main result areas; (i) Increase Human Security, (ii) Improve Sustainable Livelihoods (iii) Strengthen Resilience and (iv) Ensure Environmental Sustainability. All four domains, influencing factors and result areas have intra- and inter-overlaps with each other, which is discussed in Sect. 4. Considering the multiple linkages among each box, the module is introduced as 'Rubik's Cube Model' for community-driven Ecosystem-based DRR.

4.1 DOMAIN 01: Development Planning (DP)

Poverty further exacerbates vulnerabilities of at-risk communities that are dependent on ecosystem services to safeguard their lives and livelihoods from disasters (Leichenko & Silva, 2014). For example, greater dependence on ecosystem services is often linked to higher vulnerability, and poverty leads to such situations (Suich et al., 2015). Therefore, integrating ecosystem management and risk reduction in development planning and implementation will be more effective to achieve the goal of resilient and sustainable livelihoods of the most vulnerable communities living in disaster prone areas.

Development activities initiated by the government, non-governmental organization, private sector, or communities at various administrative levels have great bearing

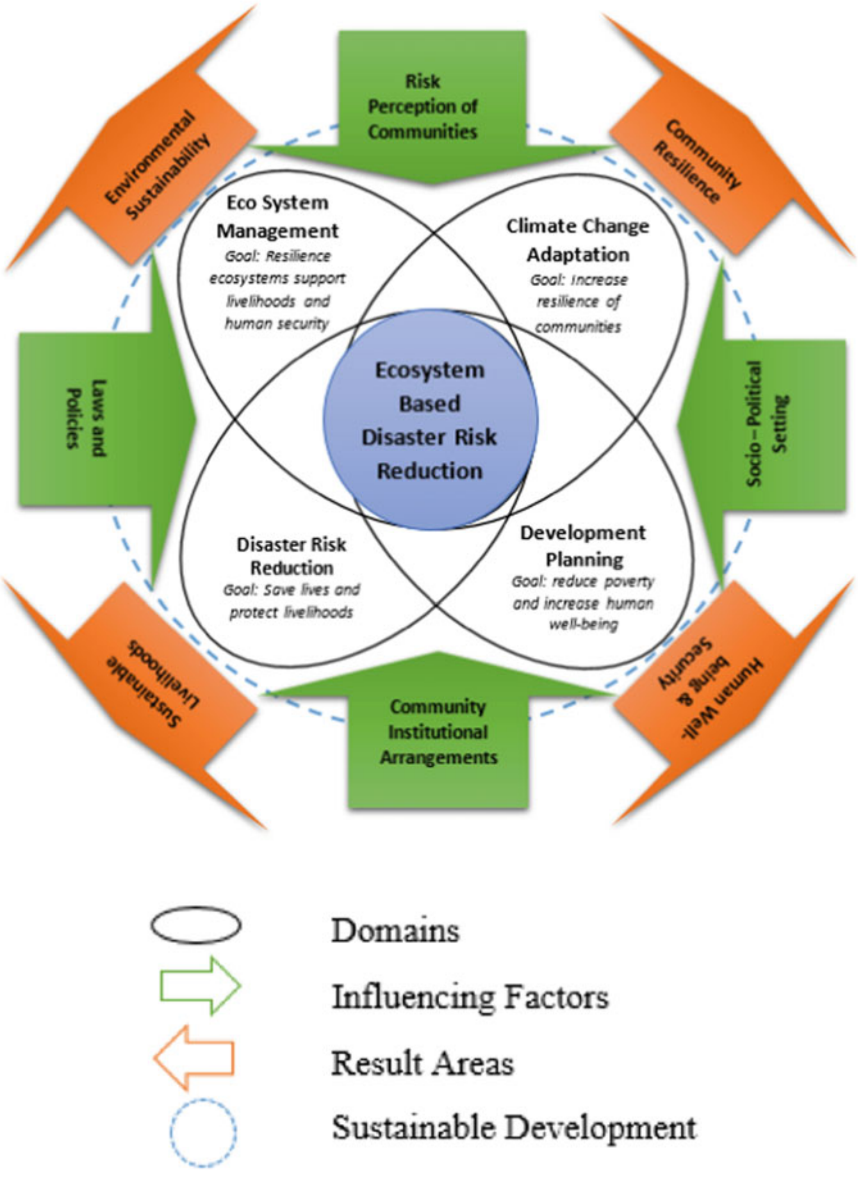

Fig. 1 Rubik's cube model for community-driven ecosystem-based DRR (Developed based on CBD (2018))

on ecosystems and hence, increase or decrease the disaster and climate risks. For example, provision of high capacity water pumps as livelihood assistance for crisis affected communities in an area with scarce ground water resources may exacerbate the vulnerability of drought, while individual household assistance for establishing rainwater harvesting systems reduces the vulnerability of drought (Ghimire et al., 2010).

4.2 DOMAIN 02: Ecosystem Management (EM/ESM)

Climate change and disasters are largely determined as to how a community executes its development intervention and manages its ecosystems. Ecosystem management (EM) can include maintaining a naturally present ecosystem and conserve and manage ecosystem for its functions (Grumbine, 1994; Yaffee, 1999). The ecosystem functions are primarily defined by natural ecological boundaries and subset of ecological structures and mechanisms that integrate social, economic, and institutional dimensions, applied in a geographical scope (De Groot, 2002).

When ecosystems such as wetlands, forests, and coastal systems are well managed, they can act as a natural infrastructure that will reduce the physical vulnerability of people to many disaster risks. Hence, an effective ecosystem will increase social and economic resilience by sustaining local livelihoods and providing essential natural resources such as food, water and building materials (Sudmeier-Rieux & Ash, 2009). Overall, an ecosystem management not only strengthens natural infrastructure and community resilience to emerging disaster risks, but also generates a range of other benefits for multiple stakeholders and results in reduced risk mitigation functions of ecosystems (Nehren et al., 2014).

4.3 DOMAIN 03: Climate Change Adaptation (CCA)

Extreme and non-extreme climate events contribute to increased hazards (Sudmeier-Rieux, 2013). They create impact on ecosystems and development planning as a result reduce the adaptive capacity. Climate-induced extreme weather events, unsustainable development practices and destruction of ecosystems contribute in increased hazards, create impacts on communities' livelihoods, and development planning that reduce the communities' adaptive capacity.

Poor communities are much more vulnerable to the impacts of climate change due to their low adaptive capacity and their disproportionate dependency on natural resources for livelihoods, specifically the natural resource-dependent rural households (Agrawal & Perrin, 2009). Environmental degradation and climate change will impact on the poor communities hardest. At the same time, development activities that may contribute for higher greenhouse gas (GHG) emissions will double their burden.

4.4 DOMAIN 04: Disaster Risk Reduction (DRR)

The impact of disasters and other social disruptions are largely determined by the extent of mitigation actions by the community and how it manages its environment, the level of preparedness to face the disruption, and the capacity to recover quickly from the tragedy. For example, the greater the depletion of people's assets lead to more vulnerability, and the more capacities and possession of productive assets people have, the more resilience they are (Moser & Satterthwaite, 2008; Sudmeier-Rieux et al., 2013). Such productive assets and capacities also include the access to and living in an environment with healthy ecosystems.

Sustainable development and DRR are considered as two sides of the same coin. Proper development planning could support the mitigation of disaster risks, improvement of the ecosystems and minimizing the climate change impacts. However, the current model of development planning profoundly alters the natural environment, often reducing biodiversity and ecosystem services, and at last threatening human wellbeing which expose communities for climate change impacts. Overall, the effectiveness of ecosystem functions should reduce the impacts due to disaster risks (Kathiresan & Rajendran, 2005; and Nel et al., 2014).

5 Inter- and Intra-Relationships Within Domains

Although Disaster Risk Reduction (DRR), Ecosystem Management (EM), Development Planning (DP), and Climate Change Adaptation (CCA) domains have specific modalities of work and targeted isolated interventions, they are closely inter-related to each other. These domains as a whole seek the primary goal of sustainable development, human well-being and human security. Hence, the ecosystem model (Fig. 1) can be further expanded to include influencing factors and result areas interconnecting each of the four domain area (Fig. 2).

5.1 Influencing Factors

Each domain is influenced by a set of factors, called influencing factors. The influencing factors are inter- related and inter-dependent, which reinforce each other. Four influencing factors include (Fig. 2):

(1) Socio-political setting
DP, CCA, DRR and ESM are highly dependent on political will. Problem related to the 'domains' continue to remain based on a political context, because it is affected by the processes of steering that are favourable to certain interests and values that are related to the political power. It is realized that although the issues related to environment, DRR, CCA, and ecosystem appear on insti-

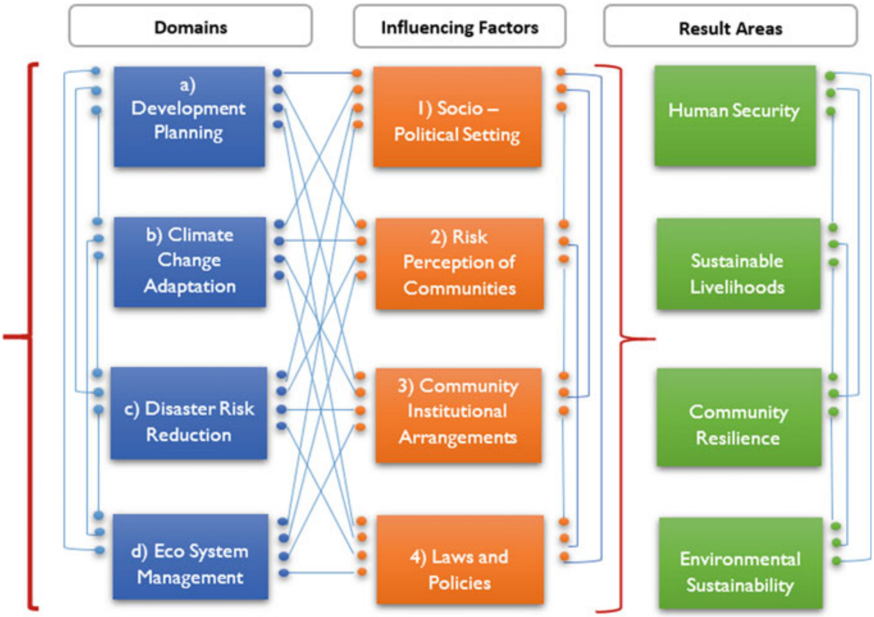

Fig. 2 Inter- and intra-relationships among domains, influencing factors and result areas

tutional policies in a number of cases, it has failed to appear in the social platforms. Community based livelihoods approaches, community belief systems, and traditional knowledge may contribute or worsen the 'domains'. Hence, collective efforts are necessary to address the 'domains'. For example, the 'sense of volunteerism' in a community plays prominent role in creating a preparedness culture and improve their adaptive capacities (Saja et al., 2018).

(2) Risk perception of communities
The risk perception of communities determines whether it adapts a proactive or reactive approach for climate change, ecological disturbances and disaster management. A proactive approach for climate change have an impact on DRR and CCA depends on 'how seriously' the communities consider environmental degradation. Disaster and climate risk perception of a community could be influenced by their past experiences, demographic characteristics, media influences, economic status, social trust among community members and government relief welfare strategies (Plapp & Werner, 2006; Ardaya et al., 2017).

(3) Community institutional arrangements
The non-structural DRR measures are mostly driven by community-based approaches, since the local commitment is the key component needed to make these DRR approaches sustainable (Marfai & King, 2008). Community based institutional arrangements such as Rural Development Societies, Women Rural Development Societies, Farmer Organisations, Disaster Management Committees and Youth Clubs increase the opportunities of participation and collective

decision making related to the 'domain' areas. Their involvement can be in the form of professional contracts, ethical or legal requirements, and fund raising activities or volunteering. It plays a facilitation role between communities and non-government/government institutions working in different 'domains'. Strength of network, advocacy and lobbying capacity, transparency, and leadership qualities of the community based organisations are some other essential components for bringing needed resources to address issues related to the 'domains' (Pfefferbaum et al., 2013).

(4) Laws and policies

The formation and implementation of favourable legal instruments and policy decisions towards a development planning (DP) that mainstream CCA, DRR and EM largely depend on political context and values. Hence, appropriate laws and policies become key influencing factors in each of the domain area for ecosystem-based DRR. The key challenges to operationalize a risk integrated development mechanism are primarily the multi-stakeholder collaboration/coordination and political will to formulate appropriate legal frameworks (Saja et al., 2020).

5.2 Result Areas

Several result areas could be generated by favourable 'influencing factors'. This leads to inter-dependent and overlapping 'result areas'. They are categorized as:

(1) Human Security: Protection of life, free from injuries, freedom from fear, access to basic needs and improved health and wellbeing could be ensured.
(2) Sustainable Livelihoods: Ensure uninterrupted livelihoods with continuous supply of inputs, store and marketing facilities.
(3) Community Resilience: Ensure ability of a community to utilize its resources and use development planning to better respond for disaster and climate change impacts.
(4) Environmental Sustainability: Prevention of environmental degradation to allow for long term ecological quality.

5.3 Tools

The institutions involved in each of the four key domain area (ESM, DRR, CCA, and DP) have their own specific mandates, implementation plan and stakeholders. However, they are closely inter-related. They are related to overarching goal of human security, sustainable livelihoods, community resilience and environmental sustainability. This arrangement allows different organisations responsible for different domain areas to utilize the same set of tools for achieving their goals (result areas). Available ecosystem-based tools and related main activities are listed in Table 1.

Table 1 Tools and relevant activities for implementation of community-driven ecosystem-based DRR

Tools	Activities
1 Integrated water management	
1.1 Household water management	Household rainwater harvesting system
	Introduce household water preservation techniques
	Recycling of household waste water
1.2 Renovation of small tanks	Participatory tank identification
	Tank bund renovation
	De-silting
	Ecological restoration of tanks
1.3 Community water resource management	Functional community based water management organization
	Prevention of water contamination
	Maintenance of water bodies
	Community monitoring mechanism
1.4 Water quality measurements	Measuring catchment ecosystem health
	Measuring fresh water quality
	Measuring estuarine water quality
	Measuring bay environmental conditions
2 Integrated forest management	
2.1 Sustainable forest management	Conservation of biological diversity
	Maintenance of forest coverage
	Maintenance of forest ecosystems
	Maintenance of forest ecosystem health
	Conservation and maintained of soil
	Conservation and maintained of water resources
	Establish legal, institutional and economic framework
	Develop forest/protected area management plans
	Establish plant nurseries
2.2 Establishing bio fence	Elephant habitat Improvement
	Community based early warning system
	Establish bio fence/plant trees and shrubs
	Introduce bee keeping
	Renovation of electric fence
	Establish plant nurseries

(continued)

Table 1 (continued)

Tools	Activities
2.3 Community forestry	Participatory forest management
	Alternative livelihoods
	Prevention of illegal encroachments
	Eco tourism
3 Integrated land use management	
3.1 Land use planning	Land use mapping
	Land use development and management plans
	Address land use conflicts
3.2 Soil conservation	Biological soil conservation
	Mechanical soil conservation
	Soil improvement
	Community based soil conservation
3.3 Landslide prevention	Biological soil conservation
	Mechanical soil conservation
	Community based early warning
4 Integrated coastal zone management	
4.1 Ecological rehabilitation/reconstruction	Restoration/rehabilitation of mangroves
	Rehabilitation of coral reef
	Protection/rehabilitation of sea grass beds
	Coastal fisheries conservation
	Coastal wetland rehabilitation/reconstruction
	Protection of sand dunes
	Coastal solid waste management
	Water quality measurements
4.2 Socio-economic rehabilitation/reconstruction	Coastal zone management plans
	Alternative livelihoods program
	Sustainable tourism
	Coastal land use planning
	Protected area management plans
5 Integrated fire management	
5.1 Land use planning	Land use mapping
	Land use development and management plans
	Address land use conflicts
5.2 Bio mass management	Forest management
5.3 Community based fire management	Train volunteers

(continued)

Table 1 (continued)

Tools	Activities
6. General tools	
	Awareness creation
	Capacity building programs
	Advocacy and lobbying
	Participatory planning
	Improve institutional capacities
	Legal and policy strengthening/formation
	Integration of social and government networks

There is a challenge in integrating the identified tools in the Rubik's Cube Model (Fig. 1) based on the domains, influencing factors, and result areas, since these tools fit in multiple domains/result areas. As a result, they were clustered during the implementation of the project in a most relevant categories, such as Integrated Water Management, Integrated Forest Management, Integrated land use management, integrated coastal zone management, and Integrated Fire Management. Further, the tools that do not fall in any of the specific thematic category were included under the category—"General Tools".

6 Concluding Remarks

A conceptual ecosystem-based DRR (Eco-DRR) model proposed in this study consists four key domains and set of inter-connected influencing factors and result areas. In general, the 'domain' areas are not mainstreamed with the functions of local governance, although the local authorities have a vital role in the 'domain' areas. They could adopt a community participatory approach for their development planning process to ensure incorporation of concerns related to the four 'domains' in the Eco-DRR model developed in this study. The inclusion of influencing factors and result areas interconnecting each of the four domains in the Eco-DRR model will make the operationalization of the model consistent and effective at the community level. Further, a set of tools that were identified in this study will guide the implementation of relevant activities to achieve the goals of community-driven DRR.

Future research is required to draw lessons from applying the set of relevant tools identified in this study to improve the model. A set of indicators for each of the result areas need to be developed to further validate the effectiveness of the ecosystem-based DRR policies for practical application at the community level. These indicators should be accompanied by multi-level decision making mechanisms to help all key domain stakeholders to prioritise the policy enforcement activities, monitor the progress, and evaluate the implementation of the targeted interventions.

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The Discourse of Municipal Solid Waste Management in Sri Lanka

Nishara Fernando and Malith De Silva

Abstract The history of Municipal Solid Waste Management (MSWM) in Sri Lanka runs to colonial times. Since then, it has undergone many changes and reforms. These modifications are the result of the changing social discourse of MSWM in the country. This paper attempts to study how the MSWM discourse has changed over time and factors that have contributed to these changes. The study incorporated a thorough policy review, which was developed using a systematic review of ordinances, acts and policies on MSWM. Further, fifteen in-depth interviews were conducted with MSWM stakeholders representing national and local level government agencies, the private sector and NGOs to collect primary data. The findings revealed that the British colonizers adopted a nuisance discourse of MSWM, which continued until the early 1980s. This led to the accumulation of MSW in rural areas and suburbs of Colombo and other major cities. As a result, in 1980 a contextual narrative defined MSWM as an environmental issue. An urban beautification contextual narrative emerged in the 2000s which reinforced the nuisance discourse on MSWM. The paper concludes that the discourse on MSWM in Sri Lanka has remained as a nuisance discourse since the colonial period to date.

Keywords Municipal solid waste management · Discourse · Social narrative · Nuisance

1 Introduction

Municipal solid waste management is a key responsibility of central governments as well as local governments. Waste management authorities utilize different technologies, strategies and mechanisms to reduce, control and manage municipal solid waste because of its significance. The social discourse on Municipal Solid Waste Management (MSWM) decides the nature of management strategies or mechanisms that the central government or local governments employs. Similar to other countries,

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the social discourse decides the nature and the direction of municipal waste management strategies in Sri Lanka. The municipal waste management strategy of Sri Lanka has changed and developed over time, incorporating new policies, technologies and techniques.

This study aims to identify the historical development of the MSWM discourse in Sri Lanka. Furthermore, the study wishes to identify the actors that shape the MSWM discourse in Sri Lanka.

2 Sri Lankan Studies on Municipal Solid Waste Management

Academics and scholars in Sri Lanka have closely studied municipal solid waste management activities as waste has created serious issues for the environment and wellbeing of the population. Academics have studied waste management under two key themes: one, the impact that discarded waste has on the environment and two, possible solutions to manage municipal solid waste management.

Arachchige et al. (2017) discuss a novel solution to resolve waste management issues in Sri Lanka. They propose that the "*conservation of natural resources as well as….protecting the environment by maintaining quality living standards can be achieved by proper waste management system*" (Arachchige et al. 2017). The authors identify "Waste to energy and landfilling" as the most promising technologies for waste management and propose a pre-drying mechanism that uses solar heating to demoisturize segregated waste. Basnayaka et al. (2019) in a book chapter titled "Solid Waste Management in Sri Lanka" discuss the prevailing waste management mechanisms and national level policy initiatives of Sri Lanka. The chapter proposes an integrated solid waste management system as the most suitable system for the country. In another article, Bandara (2008) analyses the impact of social and economic factors of waste generation. The article titled "Municipal solid waste—a case study of Sri Lanka (Bandara, 2008) identifies the major impacts that the prevailing mismanagement of waste has on the environment and the health of communities.

According to her, the current waste disposal practices have threatened many ecologically valuable habitats such as wetlands and this has reduced the flood retention capacity in many suburban areas. She also describes emission of landfill gases and leachate as a major evil of open dumping citing and its significant contribution to the greenhouse gas budget of Sri Lanka. All these studies focus on valuable aspects relevant to MSWM. However, none make an attempt to analyses the social discourse hidden within the administrative architecture and policies. The discourse on MSWM decides the effectiveness of measures introduced to manage municipal waste. Therefore, this study provides officials, practitioners and policy makers an opportunity to comprehend the nuances of the MSWM discourse and adapt their policies and programmes accordingly.

Further, the study has gathered data from majority of key stakeholders such as National level officials, officials from Municipal councils, informal waste collectors and private sector waste collectors. As a result, the analysis provides a comprehensive and holistic picture of the discourse on MSWM. In addition, the study explores MSWM activities in the Dehiwala-Mt. Lavinia Municipal Council and the Boralesgamuwa Urban Council areas. Therefore, the findings of the study are useful for local councils to reframe their waste management activities to provide a better service to their citizens.

3 Methodology

The study used secondary data sources such as ordinances, acts, policies etc. to study the social narratives on municipal solid waste management in Sri Lanka. Accordingly, authors analyzed all secondary data sources on municipal solid waste management using a systematic review method. Secondly, the study used primary data which was collected during in-depth interviews with fifteen national and local level experts, government officials, practitioners and policy makers. The research team recorded all the interviews after obtaining informed consent from respondents and was later transcribed using word processing software. Data was analyzed using the discourse analysis method.

4 The Social Discourse Analysis

Sociologists define discourses as any practice to which individuals instill meaning to understand the world around them (Metzidakis, 2000). Moreover, discourses promote understanding of social reality as a subjective orientation of social action. The subjective orientation of the actions of an individual is not completely subjective, instead the narratives that guide individual actions are mostly socially produced and shared patterns (SCHUTZ, 1974).

Sociologists have a keen interest in understanding verbal discourse, as it is the most direct form of discourse. In other words, analysts have to translate other forms of discourses to verbal form in order to comprehend other forms of discourses. Such practices can be tricky as personal biases and subjective beliefs might corrupt the translation. (Spannagel et al., 2005; Metzidakis, 2000).

There are three levels to a discourse analysis: a textual level, a contextual level and an interpretive level. Textual analysis is used to characterize a discourse as it focuses on the wording and text; the contextual level of analysis contextualizes the discourse and the third and final level of analysis is interpretive analysis where the contextualized texts are analysed to reveal social narratives (Metzidakis, 2000).

5 Municipal Solid Waste Management Discourse in Sri Lanka

The first section of the paper discusses the social discourse narratives that emerged from secondary data sources, which include policy documents developed by the parliament and other responsible authorities. The policy documents under consideration were:

- The Urban Council Ordinance (1939)—**Sections 118,119 and 120**
- The Municipal Council Ordinance (1947)—**Sections 129–131**
- The National Environment Act (1980)—**Sections 33**
- The Pradeshiya Saba Act (1987)—**Sections 93–95**
- The National Solid Waste Management Policy (2007).

The researchers attempted to identify social narratives of MSWM by paying special attention to how waste was defined, how issues are identified and how solutions are provided in each document.

6 The Nuisance Narrative

The narrative presented in the Urban Councils Ordinance suggests that waste management is the sole responsibility of the council; it fails to identify household waste producers, large-scale waste producers or the central government as additional key stakeholders in MSWM. Under the British rule in 1939, Ceylon had very few urban centers created for the benefit of the colonizers, and households of ordinary people were able to take care of their own waste until the stage of treatment and disposal. In the colonial period, there was no overconsumption and hardly any non-biodegradable wastes. However, with the introduction of missionary education, an urban, educated upper class emerged (Jayawardena, 2000) adopting, the lifestyles of the colonizers including overconsumption. This resulted in the gradual increase in the production of solid waste in the country. Ultimately, the British rulers felt it necessary to introduce a waste management component in the Urban Councils Ordinance in 1939.

This ordinance defines municipal solid waste as "All street refuse, house refuse, to be night-soil, or other similar matter" (Urban Councils Ordinance, 1939). It identifies waste as any material that is used and disposed to the streets by households. The ordinance does not take large-scale producers of waste such as hotels and factories into account.

The ordinance identifies three key components of MSWM.

- Cleaning—"for properly sweeping and cleansing the streets, including the footways"
- Collection—"for collecting and removing all street refuse"
- Disposal—"proper disposal of all street refuse, house refuse, and night-soil all refuse".

Furthermore, it is interesting to note that Sect. 120 of the ordinance identifies waste as a ‘nuisance’:

> Every Urban Council shall, from time to time, provide suitable places convenient for the proper disposal of all street refuse, house refuse, night-soil, and similar matter removed in accordance with the provisions of this Part, and for keeping all vehicles, animals, implements, and other things required for that purpose or for any of the other purposes of this Ordinance, and shall take all such measures and precautions as may be necessary to ensure that no such refuse, night-soil, or similar matter removed in accordance with the provisions of this Part is disposed of in such a way as to cause a nuisance. (Urban Councils Ordinance, 1939)

Today, such ‘nuisance discourses’ are associated with upper middleclass and middleclass norms (Ghertner, 2008) in South Asia. This nuisance approach is the dominant social narrative in the Urban Councils Ordinance. When a society or community needs to resolve a nuisance, the general approach is to get rid of it and the same applies to waste. “Every Urban Council shall, from time to time, provide suitable places convenient for the proper disposal of all street refuse, house refuse and night-soil”, signifies that disposal should be carried out in places which are “out of sight”. This means that the urban councils were responsible for providing land outside the urban area to dispose waste. Another term that reveals this nuisance narrative is the term “proper.” The term “proper” refers to appropriate disposal of waste in a location, which is out of sight of the educated, middle class and the ruling British. For an example, the municipal solid waste collected in 1939 had been disposed at two locations in Colombo and Mt. Lavinia. Kirulapone, which was a less populated area, nearly ten kilometers away from the Colombo city area was the disposal site in Colombo. Collected waste was burned using a “Refuse Destructor”, a 32-horse power liquid fuel engine incinerator. The other incinerator was located down Prince of Wales Avenue in Mount Lavinia, which was also a less populated area in the 1940s. The waste incineration facility is located nearly fifteen kilometers away from the Colombo city center (CMC, 1939; 1940). However, the other suburbs had not developed and mass scale waste generation took place only in the Colombo Municipal Council area by this period.

In 1960, the Colombo Municipal Council stopped using incinerators due to high operation and maintenance costs. According to the Report of the Commissioner of the Colombo Municipal Council, (1962) the total cost of operating and maintaining the incineration facilities amounted to 333,699 rupees which was four percent of the total budget of the municipal council.

After discontinuing the incineration facility, the Colombo Municipal Council resorted to dump municipal solid waste in privately owned lands in Muthurajawela, Kirulapana and Aththidiya areas (CMC, 1962). All these places are located at a significant distance away from the Colombo Municipal Council area.

This nuisance narrative has had a long-term effect on the waste management process of the country as the open dumping sites selected by the Municipal Councils were marshy lands or paddy land outside the immediate boundaries of urban centers. It is interesting to notice that this nuisance narrative advocated by the Urban Councils Ordinance is still the accepted policy approach of local governments. The Municipal Councils Ordinance (1947) and the Pradeshiya Saba Act of (1987) have adopted

Sections 118–120 of the Urban Councils Ordinance just as they are. As a result, the harmful waste disposal discourse "out of sight, out of mind" followed by the colonizers continued and resulted in the creation of large garbage mountains in locations including Blouemandel, Meethotamulla and Karadiyana.

7 The Environmental Management Narrative

A shift from the nuisance social narratives emerged in the National Environmental Act, implemented in the 1980s. The act established a special waste management unit under the Ministry of Mahaweli Development and Environment titled "Hazardous Waste and Chemical Management". This move to establish a unit to manage and preside over waste management under the Ministry of Environment indicates that waste became an environmental issue for the first time in 1980.

The act defines waste in the following manner:

"Waste includes any matter prescribed to be waste and any matter, whether liquid, solid, gaseous, or radioactive, which is discharged, emitted, or deposited in the environment in such volume, constituency or manner as to cause an alteration of the environment" (National Environmental Act 1980). The act implemented a new waste management unit, but it did not have any direct impact on MSWM as it had no jurisdiction over local governments. Local governments, on their part, continued the nuisance discourse advocated by previous policies.

In 2007, however, the Central Environmental Authority developed a National Waste Management Policy. The policy (as stated in its introduction) was an attempt to "develop an appropriate national policy on holistic waste management" (NWMP, 2007). The policy introduces novel technical approaches, management structures and mechanisms to increase efficiency and effectiveness. It defines waste management as an intricate, complex activity, which requires expertise and knowledge in the fields of:

I. Technology
II. Management
III. Public Relations
IV. Marketing
V. Administration.

This policy in turn shifted a significant amount of power and responsibilities from Local Authorities. Even though the policy introduces community members as key stakeholders in MSWM, it does not advocate community centric waste management. Rather, it gives the community a very limited role.

"The mandatory community involvement in managing waste is a significant input to ensure that waste managers perform their duties with the highest degree of accountability and responsibility around the country." (NWMP, 2007).

The sole responsibility of the community is to be vigilant and observe the efficiency and accountability of the local governments. The policy considers MSWM as a technical issue, which can be resolved using technical solutions. The solutions brought in by this technical narrative include the introduction of new technologies and machinery to manage the collection of waste, managing disposal sites and upgrading of staff capacity through training. The approach does not take social aspects such as cultural practices, consumption patterns and demographic specifications into account though they are significant components of waste management. Ignoring these factors can have a lasting impact on the solutions proposed to resolve waste management issues. In addition, it must be mentioned that although new technologies were introduced to waste management activities the discourse remained the same as waste management authorities continued to practice the “out of sight, out of Mind” discourse of the colonial period.

8 Co-existence of Narratives

In this section, we discuss all the policy documents available on waste management. The oldest document, the Urban Councils Ordinance of 1939 is still in effect, with no major changes to the laws on MSWM. The Municipal Councils Ordinance and the Pradeshiya Saba Acts, (1947 and 1987), adopted Sections 118–120 of the Urban Councils Ordinance word by word. This suggests that what in recent critical urban studies literature has been identified as a middle class social narrative of waste being a nuisance had underpinned waste policy in Sri Lanka from 1939 to 1987. This narrative asserts that the problem of waste should be resolved by following the “out of sight- out of mind”. Even though the Central Environmental Act introduces an “environmental” and “management” discourse of waste in 1980, the nuisance approach introduced by the Urban Councils Ordinance is still in effect. The introduction of the National Solid Waste Management Policy of (2007), too, embodies an environmental and managerial narrative but the policy acts only as a guiding principal since local governments have no jurisdiction over them.

Other than a nuisance, MSW is an environmental and managerial issue that is resolvable through technical interventions. Therefore, the official waste discourse introduced by the earliest policies has shifted away from the idea of waste been a nuisance only to a limited extent.

9 Narratives Emerging from Verbal Accounts

The research team also used in-depth interviews conducted with key informants, mostly government officials but also private company actors who have established Public–Private Partnerships with municipalities, to comprehend the nature of the waste discourse post 2007. The authors paid special attention to the impact that the collapse of the Meethotamula garbage dump had on the MSWM discourse. The key informants included seven high-ranking officers at national and provincial level agencies, such as the Central Environmental Authority, the National Solid Waste Management Support Centre, the Environmental Police, the Western Province Solid Waste Management Authority, and the Ministry of Mega Polis and Western Province Development; six elected members and government officers from Dehiwala-Mt. Lavinia Municipal Council and Boralesgamuwa Urban Council; and four managers and owners of local private waste management companies.

As discussed in the previous section, the discourse narrative revealed by the existing policy documents suggests that waste is still regarded as a nuisance and additionally as an environmental issue that requires expert solutions. However, the key informants had a different narrative on MSWM. The interviews suggest that waste is a key responsibility of modern governance and a valuable source of income for the country. The following section discusses the MSWM narratives of national and local level officials.

10 Narratives of National and Provincial Level Officers

As mentioned earlier, national level key informant interviews conducted with selected officials of the Central Environmental Authority, Ministry of Megapolis and Western Province Development, National Solid Waste Management Support Centre, the Environmental police of Sri Lanka, and the Western Province Solid Waste Management Authority revealed new narratives.

A recurrent narrative that emerged from the interviews with officials of the central government is that waste management is a key responsibility of the government. An officer of the Central Environment authority stated the following:

"We at the Central Environmental Authority understand the significance of municipal waste management and this is why we have a dedicated center to generate policy guidelines and to monitor the activities of the provincial and local level authorities and councils. If the waste management system fails for a day it is enough to create a serious disturbance to the day today activities of citizens, the government and private sector activities" (KII Interviews, 2019).

Another executive officer at the National Solid Waste Management Support Centre of the Ministry of Public Administration and Home Affairs expressed the same narrative.

"Waste management is a key responsibility of the government; this is why the government has established multiple organizations to manage the MSWM activities. At the national level we have the Central Environmental Authority, the Urban Development Authority, Ministry of Mega Polis and Western Province Development and National Solid Waste Management Support Centre to take care of waste management and improve the efficiency of the services provided to the masses" (KII Interviews, 2019).

Another narrative that emerged from the interviews with national level officials revealed that they view waste as a resource and an income earning opportunity.

According to an executive officer of the Ministry of Mega police and Western Province Development, waste is an opportunity.

"I believe that the time has passed where we viewed waste as a burden. In this era, we see waste as an opportunity; an asset. If waste is managed using the correct techniques we can earn from each bit of waste, bio-degradable waste can be turned into compost manure and non-biodegradable waste can be used for recycling. If we tap into the potential of waste, our waste management system will be self-sustaining. It will also be one of the main income sources of the local councils. Our problem is that we do not manage MSW well. If we manage it properly the opportunities are endless" (KII Interviews, 2019).

An official of the Western Province Solid Waste Management expressed a similar idea:

"With new technology and innovation in composting and recycling such as one day composting we have come to understand that waste is not waste in reality. By managing different types of waste, we can use waste to improve the lives of Sri Lankan citizens. Plastic can be recycled into new plastic material, (e.g. pavement blocks), carbonic waste can be turned into compost. Currently we have a very successful composting facility at the Karadiyana Waste Resource Centre. It has reached its full capacity in production and still cannot provide an adequate supply for the demand. We currently export 450 MT of compost to Maldives" (In-depth Interviews, 2020).

Another national level official had a similar opinion. According to him, the government wishes to reduce the burden of waste on the environment by promoting segregation at source and recycling levels.

"The way we had deposed waste in the past is a key factor that has contributed to the pollution of the environment and accumulation of mountains of garbage. The government wants to see a change in this and that is why the government introduced strict waste disposal laws in the recent years. By doing so we expect that the public will resort to dispose their waste in more environment friendly ways by segregating waste at home and handing it over to municipal council tractors. Segregated waste becomes a resource if properly managed. Also the compost can be used to reduce the use of artificial compost in farming which would also significantly reduce the cost that the government has to bare to import artificial manure" (KII Interviews, 2020).

11 Narrative of the Local Level Officials

Our data suggests that the narrative of local level officials is somewhat similar to the narratives of national level officials. For instance, local level officials also regarded MSWM as a key responsibility of the local government, as an official of the Boralesgamuwa Urban Council stated that:

"Managing waste is a key responsibility of the council; after all municipal waste is generated by community members of each urban council. We have to manage it. Unlike before, now we can earn from waste. So we see it as an asset and we are focusing on providing an optimal service to our community while obtaining the highest possible income from waste" (In-depth Interviews, 2020).

The quote also reveals a managerial narrative on MSWM, which promotes the use of waste as a resource to reduce operational and management costs. This cost-cutting narrative is a characteristic of the neoliberal governance in Sri Lanka.

This narrative of waste as a resource also emerged in an interview with an executive from the Dehiwala Mt. Lavinia Municipal Council:

"Our wards generate a large amount of waste on a daily basis. We have both a highly urbanized Dehiwala City area and a popular tourist destination—Mt. Lavinia is under our purview. As we spend more than 10 million rupees each month, we have decided to earn as much as possible from recyclable and reusable waste in the future. We have already invested money to open a large recycling center in Mt. Lavinia in the future" (In-depth Interviews, 2020).

12 Current Discourses: Waste as Resource, Waste Management for Beautification

These interviews suggest that the definition of waste by key informants is different to the narratives revealed from policy documents. The narrative presented here defines waste as a resource or an asset. This narrative seems to have developed due to many factors. As mentioned by an official from the Western Province Waste Management Authority, the introduction of new technology and innovation has played a key role in the change of the narrative. The technical developments in recycling—from producing recycled items to generating electricity—have gradually reached the Sri Lankan waste management system. These technologies have converted smelly and dirty waste into a profitable source of income. The Sri Lankan waste management authorities of the central, provincial and local governments have adopted this narrative with open arms.

Nevertheless, the nuisance narrative has not disappeared completely, as one of the interviewed mayors stated:

> We are always attempting to keep the city clean. Our collection vehicles always start from the city center and clean all the waste that is piled up on the roadsides of the city. When people go to work the city should look clean and beautiful. (In-depth Interviews, 2020)

An officer of the Central Environmental Authority made a similar statement:

> Waste is not a nice thing to look at. We always instruct the councils to keep cities clean and pleasant. The previous government invested a lot in city beautification projects. The small streams flowing through the cities of Bellanwila and Kotte were cleaned thoroughly. Previously these locations were filled with PET bottles, beer cans and even garbage bags thrown by community members. The Urban Development Authority created a new walking path and a bicycle track there. (In-depth Interviews, 2020)

These statements suggest that the nuisance narrative is still present despite the positive definitions given to waste. Now, waste is a nuisance as it affects the beauty of the city. The government of former President Mr. Mahinda Rajapaksa invested heavily on beautification projects in the metro Colombo region as well as in sub-urban areas such as Kotte, Bellanwilla and Baththaramulla. One of the key initiatives of these beautification programmes was to get rid of waste from cities and to manage them outside these territories.

The present President, his Excellency Gotabaya Rajapaksa, (then- Secretary of Defense) led this movement, committing himself to make Colombo the 'Green City of Asia'. This beautification narrative seemed to have influenced officials at all levels heavily.

To sum up, the narrative on waste has become more positive although the definition of waste as a nuisance is still prominent in the discourse due to the influence of beautification projects carried out by the previous central government.

13 The Key Actors of MSWM Discourse

The analysis of the secondary data revealed key actors of the MSWM discourse in Sri Lanka. The secondary data identifies the government of Sri Lanka as the most prominent actor in shaping the MSWM discourse. The 1939 Urban Council Ordinance was the first instance when the central government had intervened in deciding municipal solid waste management in Sri Lanka. The 1939 colonial government introduced the Urban Council Ordinance to manage municipal solid waste in the cities of Colombo, Kandy and Galle. However, the ordinance did not establish a specialized organization to manage municipal waste management. It is in the year 1980 that the government established the Central Environmental Authority which was a specialized organization with waste management as a key responsibility. Moreover, in the year 1999 the Western Provincial Council established the Western Province Waste Management Authority as a specialized organization to manage waste management issues in the western province. However, the Central Government of Sri Lanka has remained the key actor in the MSWM discourse, as provincial and municipal level organizations do not have the power to shape the national discourse on MSWM.

The key informant interviews identified that the collapse of the Meethotamulla waste mountain was instrumental in convincing responsible authorities, politicians and Sri Lankan citizens that the existing MSWM system made waste a serious issue. Accordingly, the Meethotamulla disaster was a major event that changed the MSWM discourse in Sri Lanka.

A ministerial consultant stated that,

> MSWM in Sri Lanka is a problem only because of the inefficient and ineffective management system. Meethotamulla was one such site that lacked a proper management system; Waste was not properly segregated. Dumping of mixed waste created a waste mountain that was over 29 m high. The collapse of the dump is a tragedy but the incident created an opportunity to drum into the heads of administers, politicians and the public that segregation is a must and that new technology has to be introduced to other open dumping sites to avoid a similar disasters from occurring. (In-depth Interviews, 2020)

An officer of the Dehiwala-Mt.Lavinia Municipal Council remarked:

We initiated a programme called 'waste segregation at the source' a few months before the Meethotamulla disaster. However waste segregation remained at 10–20%. After the disaster struck, this percentage increased to nearly 60% immediately. For the first time, the people, especially individuals living in the urban areas began to see how improper waste management can create serious issues" (In-depth Interviews, 2020). Another officer of the Central Environmental Authority stated that the Meethotamulla disaster played a key role in improving the waste management system in the Colombo district.

> Prior to the Meethotamulla disaster, the Kesbawa Urban Council managed the Karadiyana open waste dumping site. However, the site was not properly managed and that created long term impacts on the environment, with the Weras ganga (a river that runs through the area) being severely polluted and communities living close to the dump suffering from illnesses. However, after the Meethotamulla disaster, the Western Province Solid Waste Management Authority took over the management of the site. The management has become better now and only segregated waste is dumped in the area. (In-depth Interviews, 2020)

These statements by key informants reveal that the Meethotamulla disaster has affected the discourse on waste management. The disaster has played a role in convincing administrative officers and the public on better waste management practices. This is evident from the dramatic increase in waste segregation at source after the disaster which is increasing steadily.

14 Conclusion

The findings suggest that the nuisance narrative has played the most influential role in shaping the municipal waste management discourse in Sri Lanka. The narrative has emerged out of the regulations of the central government of Sri Lanka. The nuisance narrative emerged in the MSWM discourse in the year 1939 under the British rule to manage municipal solid waste generated in a few urban centers. Despite this limitation, the preceding governments of Sri Lanka continued the nuisance narrative. In the year 1980 a new narrative of environmental pollution emerged within the nuisance discourse with the introduction of the Environment Act. This new narrative justified the "out of sight-out of mind" nuisance narrative of the MSWM discourse and supported the continuation of the narrative. In the late 2000s the central government of Sri Lanka introduced an "urban beautification" narrative to the MSWM discourse which further reinforced the nuisance narrative of municipal Solid Waste Management in Sri Lanka.

Another narrative defines waste as a resource or an asset. This narrative seems to have developed due to the introduction of new technology and innovation. The technical developments in recycling—from producing recycled items to generating electricity—have gradually reached the Sri Lankan waste management system. These technologies have converted smelly and dirty waste into a profitable source of income.

In conclusion, the Municipal Solid Waste Management discourse of Sri Lanka can be defined as a nuisance discourse reinforced by contextual narratives such as environmental issues and urban beautification. However, there is a rising narrative among officials involved in the MSWM that defines waste as a profit making commodity and an asset.

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Qualitative and Quantitative Assessment of Plastic Debris in the Coastal Eco System of Matara District, Sri Lanka

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Abstract The current study was conducted to assess the types and amounts of plastic waste accumulated in the marine beaches and mangrove forest in Matara district, Southern Sri Lanka. Monitoring was conducted during October–November 2019 selecting five beach sites. The type and quantity of plastics accumulation in the sites were monitored in weekly intervals. The role played by local communities (Fisherman, villagers, hoteliers, NGOs and local authorities) to control the plastic accumulation in the marine environment was also evaluated through face to face semi structured interviews. Findings revealed that coastal plastic has become a barrier in maintaining both the aesthetic and environmental health of the coastline. This in turn impacted the local communities who relied on tourism and fishing. The study showed that most of the accumulated plastics on coastlines were polyolefins, polystyrene and other "float plastics". Plastic debris have migrated through waterways from inland to the ocean. Local community actions such as beach cleaning and burning of plastic wastes have provided only temporary solutions. Therefore, more progressive measures are needed to be conducted to give sustainable solutions to coastal plastics. This could be achieved through education programs for all stakeholders involved in the plastic's journey in the marine environment. Complementary solutions would be the provision of alternatives by devising technological solutions to divert plastic from the environment.

Keywords Coastal plastic · Community engagement · Coastal Ecosystems · Mangroves

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1 Introduction to the Problem

1.1 Global Level

Within the last few decades plastic became a major production and packaging material in the world. This was because of the low price, light weight, durability, strong, corrosion resist nature and ability to use in diverse applications, (Lee et al., 2013; Nor & Obbard, 2014). However, the lack of proper waste management process and improper plastic littering have resulted in high accumulation of plastic in the environment as well as those have led to pollution of the environment, especially in marine/coastal environment (Lebreton et al., 2017). Where the plastic particles contribute 60–80% of the marine litter, some regions even reach the limit of 90–95% (Xanthos & Walker, 2017). Majority of this plastic debris originate from land-based sources (Eerkes-Medrano et al., 2015). Considering the vital role of plastics played in modern society and the properties of plastics, it is unlikely that the use of plastic will be restricted anytime soon (Löhr et al., 2017).

Plastic and synthetic materials are the most common among marine debris (Sheavly, 2005). Most abundant plastic debris include Bottle caps, small sachets, syringes, paste tubes, straws, pens, plastic bits, beads, hairclips, plastic and nylon ropes, thermocol and sponges (Sulochanan et al., 2013). Apart from plastic debris, plastic pollution of oceans is dominated by microplastics which are quite stable particles (Hidalgo-ruz et al., 2012). These plastics can travel immense distances and once they settle in sediments they may persist for a very long time (Goldberg, 1997).

The geographies of countries play an important role in marine plastics. Jambeck et al. (2015) reveals that 83% of 4.8–12.7 million tons of land-based plastic that ends in the oceans originate from 20 countries out of the 192 coastal countries. Plastic waste gets accumulated through drainage canals, anthropogenic activities within the coastal areas (direct dumping, shipping, recreational activities, etc.), natural processes (currents, waves, tides & wind) and animal activities (Nor & Obbard, 2014). This interfere with human use of marine and coastal environments, marine biota and the human wellbeing.

1.2 Sri Lanka

Sri Lanka is an island situated in the Indian ocean with an area of 65,610 Km^2. It is a developing country with a population of 21 million and a per capita GNI of $3,991 (Central Bank of Sri Lanka, 2019). Due to low cost and availability, plastics are highly used in Sri Lanka. Although there are alternative materials for plastic which are identified and used in several countries, plastic invasion is still a larger problem for developing countries (Barra & González, 2018). Sri Lanka imports about 160,000 metric tons of plastic raw materials annually and another 100,000 metric tons of plastic comes as intermediary and finished goods for consumption (Gunarathna et al., 2010). This comprises 20–25 types of plastics (Lakmali & Dissanayake, 2008).

In Sri Lanka, the basic framework required to manage solid waste is given under the Provincial Council and Local Authority regulation and legislation, Urban Council and Municipal Council ordinance, Pradeshiya Sabha and National Environmental Act. According to these, the management of Municipal Solid Waste (MSW) is the responsibility of Local Authorities. However, only 2500 tons of MSW is collected out of 6400 tons of waste generated per day (UNEP, 2001). As a result, illegal dumping and waste burning can be commonly observed (Vidanaarachchi et al., 2006). This pose a significant health risk due to increase in rodents and atmospheric pollution from burning plastics (Zon & Siriwardana, 2000).

The actions taken to mitigate plastic pollution through Sri Lankan plastic recycling industries seem to be ineffective as they run under capacity due to insufficient collection of plastic materials. The reason for this is not lack of plastic waste but the lack of standard ways for plastic sorting, problems of cleaning, problems in obtaining Environmental Protection License and access to proper sites (Gunarathna et al., 2010). Moreover, the Sri Lankan recycling industry poses a threat to environment because untreated wastewater from cleaning plastic waste is released into waterways by adding to the problem (Jayasekara, 2010).

According to Jambeck et al. (2015) Sri Lanka is ranked 5th in plastic polluter of oceans. Sources of plastic accumulation in coastal belt includes harbor operational activities, residential actions and recreational events (Athapaththu et al., 2019). Plastic accumulation creates many problems to livelihoods of people living along the coastal belt (Sandilyan & Kathiresan, 2012). Therefore, it is worthy to study the nature of this problem. An island wide survey conducted by Chang et al. (2018) revealed that on average 4.1 large (>25 mm) and 158 small (5–25 mm) pieces of debris can be found per square meter of beach and out of which 93% is plastic. The highest density of plastic accumulation was reported in southern costal line (Jang et al., 2018). Therefore the current study was conducted in beaches of the Matara District with the objectives of quantifying and assessing types of plastic accumulation, assessing the level of community involvement in managing coastal plastic and discovering possible solutions forwarded by stakeholders involved in the plastic journey.

2 Methodology

2.1 Beach Survey

After an initial inquiry, five locations in the coastal belt of Matara district; Weligama beach, Polwatumodara estuary, Thotamuna-Niwala River mouth, Wellamadama beach and Wellamadama lagoon were selected (Figs. 1 and 2). The sampling sites

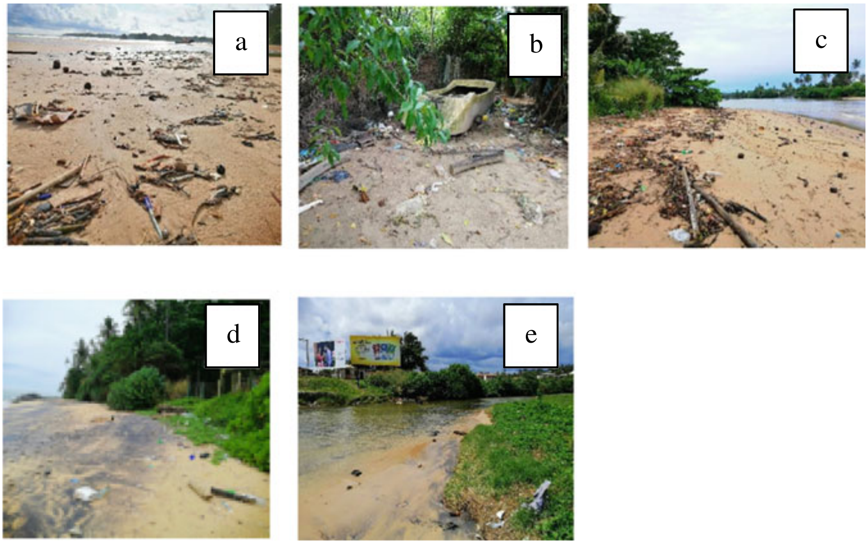
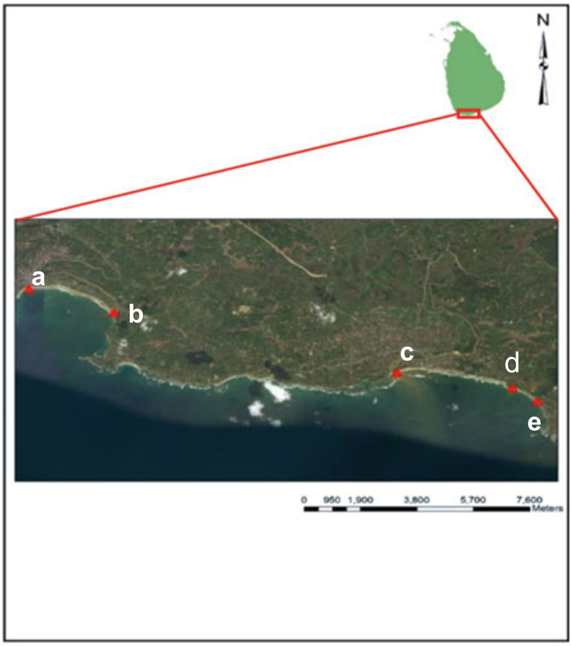


Fig. 1 Selected sites and litter accumulation **a** Weligama beach, **b** Polwatumodara estuary, **c** Thotamuna estuary/Nilwala river mouth, **d** Wellamadama beach, **e** Wellamadama lagoon

Fig. 2 Study Area (**a** Weligama beach, **b** Polwathumodara lagoon, **c** Thotamuna/ Nilwala Estuary, **d** Wellamadama beach, **e** Wellamadama lagoon)



were very diverse and included sandy beaches isolated from direct human influence, beaches with popular tourist activities, lagoon and estuaries. There were two sites associated with mangroves (*Bruguiera* sp.), Wellamadama lagoon and Polwatumodara estuary.

The survey was conducted for four weeks, from 27 October 2019 to 24 November 2019 and sampling was done once a week. In each location three replicates of 10× 10 sq. m were randomly selected, within a replicate 1 × 1 m^2 quadrant were marked along the diagonal. The plastic and polythene debris found within the quadrat (1 × 1 m^2) were collected and counted in the field, while identifying their types and size. Meanwhile all debris (including organic matter) were removed from 10 m × 10 m quadrat and data were collected in the time period of every 5 days (Lee et al., 2013; Chang et al., 2018).

Collected samples were categorized into 4 groups: pre-disposal usage types including end consumer products, packaging material, fishery-related material, and other materials. Here, end-consumer products were items discarded by consumers after use (e.g., toothbrushes, pens, straws). Packaging material included those products manufactured for wrapping, containment, protection, handling, delivery, and presentation of goods from the producer to the consumer (e.g., food wrappers, water bottles, ice cream cups) (Chang et al., 2018). The products used in fishing, vessel particles and containers that carry fish (e.g., Polystyrene, nylon ropes, fishing nets) were categorized as fishery related materials. Clinical waste and particles (breakdown of larger plastic pieces) were included in other material category (e.g., syringes, saline bottles, polythene particle) (Sivaramanan & Kotagama, 2018).

2.2 Social Survey

Social survey has been done with the participation of diverse group of people including villagers, fishermen, hoteliers, NGO's, government institutes and university academics. Semi structured interviews were conducted to identify the impact of coastal plastic in day today life and their contribution for managing the problem and their effectiveness. The survey sampling frame was focused at local users of the coastal area such as fishermen, hoteliers, tourists and villagers (Fig. 3) and responsible government institutes; Marine Environment Protection Agency (MEPA), Matara Municipal Council (MMC), Coast Conservation and Coastal Resources Management Department (CCD) and Sri Lanka Coast Guard (Mirissa).

Individuals who frequently stroll near each site was also interviewed face-to-face with their consent according to Halkos and Matsiori (2012) and Slavin et al. (2012). Before the interviews, an appointment was made and on the day of the interview their verbal consent was taken.

Apart from above, two workshops with round table discussions were conducted on 25th November 2019 in Colombo and 26th November 2019 in Matara to gather information, ideas and suggestions on managing coastal plastic. The workshops targeted approximately 40 diverse participants. The survey questions incorporated

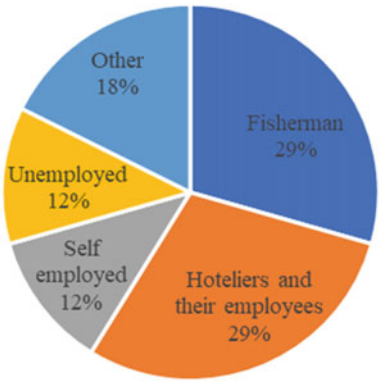


Fig. 3 Profiles of respondents in coastal communities

the aspects given in the chart, aiming to assess people's behavior on littering, reasons for plastic pollution in coastal area, their actions to manage the plastic pollution and their suggestions (Willis et al., 2018).

Interview questions of the semi structured interviews related to the social survey of the study:

- Name and occupation of the participant
- What is your perception of plastic?
- How do you see the problem of coastal plastic?
- How have coastal plastic interfered in your day today lives
- What actions have you taken in your capacity to address the issue of coastal plastic?
- What are the costs associated with above actions?
- How effective are above actions?

3 Findings

3.1 Beach Survey

Average number of plastic items per week that accumulated within the period in selected sites are given in the Table 1. Accordingly, Other items (breakdown of larger plastic pieces & clinical waste) were the abundant type of plastic wastes in Weligama beach, Thotamuna estuary and Wellamadama lagoon. Fisheries related material were the highly concentrated plastic items observed in Wellamadama beach. The litter accumulation during the 4-week survey period is given in Fig. 4 which demonstrated high fluctuations of accumulation levels in each site. A high level of plastic waste accumulation was observed in the 1st week. This could be due to long accumulated debris in the sites in off season. However, there was an overall drop in the quantity of plastic accumulated towards the end of the month. This could be due to beach

Table 1 Average number of plastic items per week that accumulated within the one-month survey period in each site

Category	Average number of plastic items (number of item/m^2/week)				
	WB	PL	TR	WL	WeB
End consumer products	27	16	25	48	15
Packaging materials	19	15	24	67	20
Fishery related materials	3	11	9	60	82
Other	63	4	31	83	18

WB Weligama Beach, **PL** Polwatumodara, **TR** Thotamuna Estuary, **WL** Wellamadama Lagoon, **WeB** Wellamadama Beach

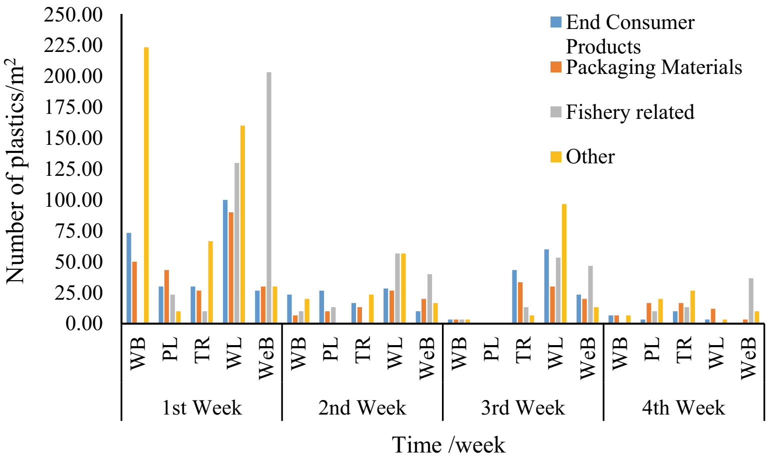


Fig. 4 Litter accumulation within the 4 weeks survey period (**WB** Weligama Beach, **PL** Polwatumodara, **TR** Thotamuna Estuary, **WL** Wellamadama Lagoon, **WeB** Wellamadama Beach)

cleanups organized by hoteliers to prepare for the tourist season. The tourist season falls between November to March in Sri Lanka (SLTDA, 2018). Further, there was a visible drop in rainfall and wave action towards the end of the period. This could also be attributed to the drop of plastic waste at the end of the month.

In the Weligama beach straws, yogurt spoons, nylon ropes and small plastic particles, toothbrushes, toys and pens were dominant. This site is a popular tourist site with frequent visitors coming for recreational activities such as surfing and swimming. Hence, litter related to recreational activities are frequent. However, the beach looks much cleaner compared to other sites due to beach cleaning by hoteliers and related businesses partners. Nevertheless, the location is heavily polluted during the rainy season due to high wave activity, coastal current and high influx through small canals (Lidia & Fischer, 2003; Amarathunga et al., 2013).

Diverse plastic items like electric equipment, sanitary items, kitchen items, and clinical waste were found in the Polwatumodara site during the rainy season and high tides. This was due to water level increase of Polwatumodara estuary as the result of the high runoff of Polwatta river and sea water intrusion (Amarathunga et al., 2013), resulting the flooding in mangrove area due to excess lagoon water. Thereafter litter gets accumulated and entangled on the roots of mangrove trees. A bridge, rock wall and net fence is available in the vicinity of the Polwatumodara site, which along with mangrove trees forces the litter closer to the edge of the estuary, blocking the drift of them towards the land as observed by Weerakkody (1993), Ecology (1998), Barnes et al. (2009), Barasarathi et al. (2014) and Ivan do Sul et al. (2014).

Debris carried by the Nilwala river is the reason for accumulation of litter at the Thotamuna surveyed site. According to Elkaduwa and Sakthivadivel (1999) there is a high runoff contribution from Nilwala river during October November rainy season with high tides contributing the floods to the estuary (Weerakkody, 1996), resulting accumulation of litter carried on by the river to the location. There are wild bushes lined along the sides of the estuary which catches some chumps that drift with river water. Research encountered accumulation of different types of litter in the Thotamuna site such as clinical waste (syringe, saline bottle, and medicine containers), sanitary items, kitchen items, etc.

PET bottles, sanitary items and polystyrene were abundant in the Wellamadama lagoon site during the study period. There was a waste dump site near this area and a fish market. Hence, birds (crows, cranes) and stray dogs were common in this area who were also responsible for waste dispersion. Furthermore, it was observed that the Dondra bridge acted as a barricade to retain waste inside the lagoon (Weerakkody, 1993).

Polystyrene, PET bottles, food wrappers, hospitals waste, and straws were common in Wellamadama beach. Polystyrene gets accumulated as the site is closer to fisheries harbor and fish market. A shipping route travers closer to the beach and ocean currents bring ship litter to the coast (Roser, 2018).

During the rainy season high flux of pollutants are observed in all the sites. As Thomas et al. 2016 and Lebreton et al. 2017 states, due to the high river runoff, waste accumulation pattern is increasing. Accordingly, beaches of Polwatumodra, Weligama and Thotamuna get high load of pollutants.

The high wave actions in Weligama and Wellamadama during the rainy season contributes more pollutes compared to mild days. However, the situation of Wellamada Lagoon behaves differently due to transferring of wastes to the sea with rain fall (Basnayake et al., 2019). Thus, the animals, wind, rain and human activities are factors contributing to plastic litter in coastal eco systems (Lidia & Fischer, 2003).

3.2 Social Survey

3.2.1 Coastal Communities

On average 3 individuals from each site were interviewed to understand how coastal plastic impacts their life and the measures taken by them to address the issue. The findings show that main methods of plastic accumulation in coastal environment is owed to plastic carried from inland water ways and littering by coastal dwellers. The participants elaborated that the improper waste disposal methods of communities living near waterways and illegal dumpsites as sources of waste accumulation besides the shores of waterways and the beaches. These findings are consistent with findings of Jayasiri et al. (2013) and Athawuda et al. (2020).

The impact of plastic on communities were mainly a problem of aesthetics. 80% of the participants mentioned that the plastic litter destroys the beauty of the beach and it hinders activities related to tourism (Kariyawasam et al., 2019; Sivaramanan & Kotagama, 2018). For example, Wellamadama Beach, Weligama Beach and Polwatumodamodara estuary are popular recreational sites. The participants are in strong opinion that plastic accumulation discourages tourists coming to the beach and thereby affecting their income from hotels and restaurants.

Disturbances to fishing activities, marine organisms and growth of mangroves were the other issues arising due to plastic contamination which is a continuous problem for their livelihood activities (Sandilyan & Kathriesan, 2012). However, the interviewees only highlighted the plastic problem as an obstacle to their daily lives. They were not aware of the long-term consequences of plastic contamination.

The communities have taken certain actions to address the plastic problem. Participants near recreational sites revealed that periodical beach cleanups are carried out to keep the beaches attractive for tourists. Sometimes there are voluntary beach cleanup programs organized by the hotel and restaurant community. The collected waste from cleanups were handed over to garbage collectors of municipal councils. Nevertheless, there is a high possibility of collected waste re-entering the water ways due to improper dumping. The Thotamuna estuary had designated plastic collectors appointed by MEPA who cleaned the Thotamuna beach daily. The next common solution was burning plastic waste and burying the remains despite the regulations banning the burning of plastics in 2017 by the Sri Lankan government. The locals were not aware of the health risk and pollution caused by burning plastic. Above actions were only giving temporary solutions as plastics keep accumulating on a periodical basis.

3.2.2 Institutional Level Contribution

MEPA, CCD, Sri Lanka Coast Guard (Mirissa) and MMC were the government institutes that have been interviewed. The MEPA act; 2008 No 35 empowers MEPA. They can take legal action against the people who dump any oil, harmful substance or other pollutant into the marine environment. MEPA have appointed few groups (10/12 members) of people with low income in coastal areas as beach care takers (8 sites in Matara District) and they conduct awareness programs for communities (fisheries, villagers, etc.), government institutions (School, police stations, etc.), and private sector organizations (hoteliers, tour guides, etc.). Further, they conduct beach cleaning programs annually in par with the *International Beach Cleaning Day* (26th of September) in many beaches around the island, some beach cleaning programs are conducted monthly as part of an action plan or as a response to a request or after observing the coastal area reach to its tolerance limit of solid wastes. MEPA joins with UN *Clean Sea Campaign*, monitor the School Marine Groups of school near coastal area, issue the hotel dumping license and monitoring and install dustbins in beach areas.

Conservation of coast and coastal resources belongs to CCD act (Coastal Conservation (Amended) Act No 49 of 2011). They also conduct beach cleaning program (jointly with MEPA) by providing both human and physical resources (poly-sac bags) for some beach cleaning programs and conduct the awareness programs on waste discharge and coastal conservation.

MMC is the key institute that manages all urban waste in Matara town area. They frequently collect plastic and polythene waste in coastal area by joining with beach cleaning programs, installs dustbins in beach side and collect the litter frequently and conduct awareness programs (workshops, leaflets, etc.). To discourage polythene, they refrain from collecting dirty polythene food wrappers (lunch sheets) and polythene bags (shopping bags). MMC owns a plastic and polythene recycling unit (Kotawila) Their waste management programs follow the concepts of 4R.

Coast guard monitors the littering activity happening under their terrain. As an action fisherman were permitted to carry only 5L bottles when they go for fishing and return of empty bottles are checked on their return.

3.2.3 Managing Coastal Plastic

Workshops held on 25th and 26th November with the participation of NGOs, government and private organizations focused on getting suggestions to minimize the problem of coastal plastic. Accordingly, all the participants agreed that a methodical educational program should be introduced to the country regarding plastic waste management. Kariyawasam et al. (2019) also argues that education regarding the impact of marine litter on the environment is necessary. Use of media was highlighted for popularizing the education programs. 40% of participants suggested building model plastic free villages and populating the concept across country. Having a legislative framework for plastic management and strict enforcement, developing and promoting businesses associated with plastic waste management, introducing plastic chopping machines to promote domestic level recycling and introduction of alternatives for plastic were other solutions forwarded by the participants during the workshops.

4 Conclusions

- Key sources of marine plastic pollution in the southern coastal belt of Sri Lanka are linked to upstream dumping into inland water ways which reaches the coastal ecosystems and inattentive littering behavior of beach users including coastal dwellers and fisherman. Anthropogenic activities, animal activities and natural processes also affect plastic distribution within the coastal area to some extent.

- The study uncovered that plastic particles (breakdown of larger plastic pieces) and clinical waste were the most abundant type of plastic debris accumulated in the southern coastal belt.
- Livelihoods and daily activities of local communities were affected by coastal plastic. The biggest impact was to the tourism and fishing industry.
- Awareness regarding long-term consequences of plastic accumulation was lacking in the local communities. The plastic accumulation was viewed only as an obstacle in their daily lives.
- Local communities have taken certain measures to address the plastic problem such as beach cleaning and burning plastic. However, these were just temporary solutions and plastic keeps accumulating on a periodical basis.
- It has been identified that lack of proper knowledge, environment responsibility and lack of proper waste management systems are reasons for coastal plastic problem in Matara district. However, prohibiting plastic manufacturing or usage is not the solution for plastic pollution.
- Sustainable solutions such as education programs for all stakeholders involved in the plastic's journey to the marine environment, provision of alternatives and devising technological solutions to divert plastic from the environment are few actions that can establish to reduce coastal plastics.

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Transboundary River Governance Practices for Flood Risk Reduction in Europe: A Review

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Abstract Transboundary rivers cross borders and create interdependencies between places. To manage problems such as flooding within a transboundary river basin, actions must be integrated from upstream to downstream. This can pose several governance challenges. The project *Mitigating Hydrometeorological Hazard Impacts Through Improved Transboundary River Management in the Ciliwung River Basin* aims to inform plans for improved transboundary river governance to tackle flood risk in the Ciliwung River Basin, Indonesia. Based on the project's conceptual framework, this chapter presents the key features of transboundary river and flood management related to three aspects: institutional, political and operational. To explore each feature in more depth, the chapter draws upon a literature review of the European region, asking *what can be learned from transboundary flood management in Europe?* Europe has many transboundary rivers and is apt to provide insights into the approaches taken and the challenges faced. The review reveals the benefits of a strong legal framework and coordinating institutions, but also several ongoing challenges including sectoral integration, participation and climate change adaptation.

1 Introduction

Floods are the most frequent and widespread natural hazard globally (Rudari, 2017). In 2019 floods accounted for nearly 50% of all natural hazard related disasters, and 43% of all disaster fatalities worldwide (CRED, 2020). Trends show there has been

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a rise in the frequency of flooding around the world, and as climate change continues to alter hydrometeorological extremes, flood events are likely to become even more frequent and severe in the future (Najibi & Devineni, 2018). The ability to mitigate and manage flooding is now more important than ever.

The practice of integrated flood risk management (IFRM) seeks to reduce the likelihood and impacts of flooding (Jha et al., 2012). The term *integrated* denotes a focus on tackling floods holistically. IFRM acknowledges that rivers are connected systems, and activities within a basin are interdependent. Therefore, it seeks to account for spatial and temporal interactions, and to unite relevant stakeholders from upstream to downstream (WMO, 2009; Serra-Llobet et al., 2016). It is now widely accepted that to achieve integration there is a need to manage basins as a whole. Yet, this ideal form of basin management exists at odds with traditional modes of governance. The world is split into administrative units defined by political borders. River basins, however, do not fit neatly into these divisions. A river basin that crosses one or more international borders is known as transboundary (UNEP-DHI & UNEP, 2016). The need to overcome political borders to effectively manage transboundary basins presents an array of complex challenges (Bracken et al., 2016).

The aim of this chapter is to highlight some of the fundamental features of transboundary river and flood management. Throughout, each is explored by drawing upon practices and experiences from the European Union (EU). It asks *what can be learned from transboundary river management experiences in Europe?* The chapter begins with a brief background to the flood problem in Europe. The methods used to conduct the review are then given. The findings are presented in terms of three overarching aspects: institutional, political and operational. A summary and discussion are given in Sect. 7.

2 Flooding in the European Context

Europe is heavily impacted by flooding. Between 1980 and 2017 flooding resulted in 4300 fatalities and approximately 170 billion Euros of economic damages, plus further impacts on the environment, human health and cultural heritage (EEA, 2019). The region has the largest number of transboundary river basins globally, covering approximately 60% of European land area. It is also home to the most international river basin, the Danube, which crosses 19 countries (Baranyai, 2019b). With its long history of flooding and international water sharing, Europe is apt for providing insights into transboundary flood management.

3 Methods

This work was conducted as part of the project *Mitigating Hydrometeorological Hazard Impacts Through Improved Transboundary River Management in the Ciliwung River Basin*. This collaborative research project between the United Kingdom and Indonesia aims to inform plans for improved transboundary river management to tackle flooding in the Ciliwung Basin, Indonesia. To gain an understanding of the complex transboundary management problem, a conceptual framework was developed. The initial framework was based upon that for the management of shared international waters proposed by Savenije and van der Zaag (2000). The framework consists of three pillars: institutional, political and operational, with integrated water management as the foundation. The current project built upon the framework, adapting it to focus on flood management.

To shed light on each aspect of the framework, the project explored the management practices of other flood affected regions of the world. European management practices were investigated through a literature review that included documents from the academic and grey literature, as well as EU documents and websites. Sources were retrieved via online searches using Google, Google Scholar and the University of Huddersfield's online library portal. Search terms included flood*; river basin; management; Europe; transboundary; cross-border. Although the primary focus was on flood management, the review also included literature from the wider field of water management. This was because there are important water management procedures that have had a substantial influence on the way river basins are managed. Due to the breadth of the topic, this chapter aims to provide an overview of the key issues and lessons learned only.

4 Institutional Aspects

4.1 Legal Frameworks

A strong legal framework is often suggested to be the basis for successful integrated basin management (Savenije & van der Zaag, 2000). Legal mechanisms set out common goals and approaches for riparian states to follow and can help to achieve consistency across the basin.

The EU operates an autonomous supranational legal system. In addition to national law, EU states are regulated by international laws ratified by the EU, EU directives, and often, further bi-/multilateral treaties (Baranyai, 2019b). International laws do not necessarily deal directly with transboundary flooding, but in some instances, set out requirements for cooperation and the reduction of transboundary impacts. This includes laws such as the Water Convention (United Nations 1992) and the Espoo Convention (United Nations 1991). The principles of the conventions have guided the application of basin treaties and institutions in some instances.

The most influential laws for European river management have been two EU directives. These are the Water Framework Directive (WFD), which seeks to improve the environmental status of river basins, and the Floods Directive (FD) that aims for a consistent approach to flood management across the EU. The main impact the directives had was the establishment of River Basin Districts (RBDs), and requirements for RBD level planning. An RBD is an area covering one or more catchments. Of the total 128 RBDs across Europe, 49 are transboundary (Jager et al., 2016). In such cases countries should coordinate their RBD plans. In this respect, the Directives have been considered drivers for cooperation on river basin planning, and have increased communication and information sharing between countries (Renner et al., 2018; Wiering et al., 2010). Despite this, some common issues have been identified. Directives set out goals but do not prescribe how they should be achieved. This provides the flexibility for countries to decide how they will integrate them into their national system. In many cases, implementation has been based around the existing institutional structures within countries. This has led to concerns over institutional gaps between countries, meaning that coordination with neighboring states may not necessarily have been eased (Renner et al., 2018; Vouvoulis et al., 2017).

A further issue surrounds practical implementation. Although the Directives have increased cooperation in the planning stages, it has not always translated well into practical action. It is possible for countries to meet the requirements of the FD, for example, through planning and assessment alone, with practical application not legally enforced (van Eerd et al., 2015). Implementation remains the responsibility of nation states (Bakker et al., 2013). Similarly, the need for transboundary cooperation is not imposed. This means that if two states fail to cooperate on their joint RBD plans there are few legal consequences (Baranyai, 2019a).

Basin treaties are another important feature of European transboundary river management. Treaties between two (bilateral) or more (multilateral) countries are common with over 100 such agreements in place for shared water bodies (Reichert, 2016). In many cases, treaties have been in place for many years, predating the WFD. They emerged for various reasons. For example, they have been established to mitigate cross-border tensions over water availability, to tackle transboundary flood and pollution issues, and to support the implementation of the WFD (UNDESA, 2013; da Silva Costa, 2018; ICPR, 2020). However, it has been suggested that the demands of the EU Directives have taken focus away from these other mechanisms that tackle a wider range of transboundary issues (Keessen et al., 2008). In some cases, treaties are accompanied by a river basin institution which supports its implementation. Further details of transboundary institutions are given in the next section.

4.2 Mechanisms for Horizontal and Vertical Coordination

Obligations for basin wide planning are set out in some of the legal frameworks noted in the previous section. This requires different parties to coordinate *horizontally* across the basin. In a transboundary setting, this may require cooperation across different political, legal, institutional and technical settings (UNEP-DHI & UNEP, 2016). Many European counties also exhibit multi-level governance structures. Often local actors are responsible for implementation, but policy is made at the national level, requiring further coordination between *vertical* levels of governance (Fournier et al., 2016). Achieving horizontal and vertical integration practically, however, can be challenging. In Europe coordinating institutions are a common feature. In transboundary settings there can be a lack of suitable communication channels between actors and responsibilities can be unclear (Skoulikaris & Zafirakou, 2019). Coordinating institutions can provide a platform for stakeholder interaction and the integration of activities (Cassel & Hinsberger, 2017; Pellegrini et al., 2019).

At the international level, there are river basin organisations (RBOs). RBOs provide institutionalised cooperation. They usually apply to a geographically defined river basin, and often are associated with a binding international agreement such as a treaty (Schmeier et al., 2016). For example, in the Danube Basin, the International Commission for the Protection of the Danube River (ICPDR) is responsible for the implementation of the basin's multilateral agreement, the Convention of Cooperation for the Protection and Sustainable Use of the Danube River (1998) (ICPDR, 2019).

RBOs have been identified as useful tools for basin-level planning (UNECE, 2009). Despite this, one issue with planning via RBOs is that often, they are too large scale to allow for participation of lower levels. To address this, further coordinating institutions can sometimes be found at the sub-basin level. Sub-basin institutions are considered beneficial for bridging between top-down and bottom-up governance and increasing opportunities for local participation. However, it is suggested that such institutions need clearer protocols on how their work can be linked and aggregated to the RBD level for the purposes of RBD level planning (Cassel & Hinsberger, 2017; Pellegrini et al., 2019). Furthermore, in contrast to RBOs, these institutions are often non-statutory and as a result can lack power and funding security (Robins et al., 2017; Aubin et al., 2019).

4.3 Participation

There has been increased attention for stakeholder and public participation in river management since it became a requirement of the WFD (Begg, 2018). Similar to other aspects of the directive, flexibility is given to Member States on how participation should be implemented. As a result, the approaches taken across Europe vary greatly. In western European countries in recent years there has been a growing trend towards citizens taking a more active role, participating in both the decision making and delivery of FRM services alongside the authorities (Mees et al., 2016). Active participation is thought to produce fairer and more effective IFRM. Although in some cases, the transfer of responsibility to the public has raised concerns over responsibility, accountability and justice (Begg, 2018). In other instances, participation is much less developed. Limited uptake of participation has been linked to a lack of flood experience, awareness and resources (Fournier et al., 2016). In general, there are concerns over this lack of balance, and the WFD goals have been criticised for being too minimal and ambiguous (Euler & Heldt, 2018; Jager et al., 2016).

5 Political Aspects

5.1 Political Will and Capacity

Political will can produce conditions that either enable or hinder transboundary cooperation (Savenije & van der Zaag, 2000). For example, this may occur through influence over relations between neighboring countries or the availability of resources allocated to flood management. In the EU, low political will has been found to hinder the implementation of transboundary disaster management policies. This was linked to countries believing they should be self-reliant, and the view that they did not need to cooperate with neighboring states (Amaratunga et al., 2017). Furthermore, levels of political will and capacity may not always be aligned either side of the border. Although the EU provides a unifying body, there is still great diversity between the countries themselves. Unequal levels of power and capacity can present a further barrier to successful cooperation (Moral & Do, 2014; Renner et al., 2018).

5.2 Sectoral Integration

For successful IFRM, different sectors need to coordinate their plans and actions throughout the river basin. European water management has been increasingly reorganised around the river basin to achieve this integration. Although this has tackled fragmentation within the water sector, there are concerns over the gap between water and other sectors. Malalignment has been identified between water and sectors such as agriculture and spatial planning. These sectors are highly relevant for IFRM, but are not basin oriented. There are concerns that this fragmentation may impede fully integrated management rather than supporting it (EEA, 2016; Moss, 2012; Tsakiris, 2015).

6 Operational Aspects

6.1 Data and Information Sharing

To form a holistic understanding of the flood problem, data of different types from different sources need to be combined. This makes data and information sharing crucial for successful IFRM. Due to the interconnectedness of river systems, upstream and downstream countries may be required to share data and information with one another. However, different official languages and data management standards can lead to the incompatibility of data sources (Amaratunga et al., 2017; Boin, 2019), and a lack of suitable data exchange mechanisms can prevent sharing of information (Miller & Douglass, 2018; Skoulikaris & Zafirakou, 2019). To overcome this, mechanisms for common data sharing and early warning have been developed for Europe. One example includes WISE (Water Information System for Europe). WISE is an online platform providing information on marine and freshwater for authorities, scientists and the public (European Commission, 2020).

6.1.1 Early Warning Mechanisms

Data and information sharing are of particular importance for early warning procedures. In transboundary basins in particular, early warning from upstream can be of vital importance for an effective response downstream. In Europe, problems with incoherent and poor-quality flood information were identified as a contributing factor to the severity of impacts during the flooding of the Danube and Elbe rivers in 2002 (Thieken et al., 2016). As a response to these floods, a pan-European forecasting system was established, known as the European Flood Awareness System (EFAS). EFAS provides Europe wide medium range weather forecasts and information to hydrological and civil protection services. The system has a particular focus on providing transboundary forecasting (ECMWF, 2019). It does this by focusing on large scale forecasts (above 2000 km^2). The forecasts are generated by the European Centre for Medium Range Weather Forecasts (ECMWF) and the information is then distributed by designated authorities. This ensures the principles of 'one voice' and the competencies and reliability of the disseminators (Smith et al., 2016).

6.2 Climate Change Adaptation

Integrating climate change adaptation (CCA) plans into transboundary river management is important for several reasons. Climate change is likely to exacerbate existing water related challenges (Zeitoun et al., 2013). Cross-border conflicts could become more frequent if existing arrangements struggle to manage further pressures (Gleick & Iceland, 2018).

The EU adopted its Strategy on Adaptation in 2013, which has increased the number of states with CCA plans (European Commission, 2018). However, a lack of attention for CCA as a transboundary issue in EU policy has been identified. For example, the WFD does not make explicit reference to climate change. Similarly, it was found that climate change considerations were missing from the majority of FD plans (Amaratunga et al., 2017; WRc, 2015). On the other hand, some RBOs have taken the initiative to develop their own plans. For example: the International Commission for the Protection of the Rhine has developed its own basin specific CCA strategy (UN & INBO, 2015). There are concerns however, over the effectiveness of such initiatives. One problem faced by RBOs is that they do not have any legally binding power on climate change, as these decisions are still made nationally (van Pelt & Swart, 2011). This potentially limits the impact of these plans.

7 Summary and Discussion

The aim of this chapter was to highlight the key aspects to be considered in transboundary flood management and identify what lessons can be learned from the experiences of the European region. Several lessons can be identified from the review.

A strong legal framework is suggested to support transboundary management. Laws provide overarching principles for countries to follow, and their legally binding nature helps to foster action. In Europe, the EU legal framework, in particular the directives, has increased cooperative river basin planning and information sharing. However, there has been less focus placed on transboundary cooperation in terms of implementation, as this remains the responsibility of individual states. European countries are not homogenous, and this approach provides the needed flexibility. On the other hand, it has the potential to reinforce gaps between countries and impede cooperation. Furthermore, the reliance on national approaches for implementation means that the success of plans is in the hands of individual nations (Bakker et al., 2013), thus is subject to political will and capacity. Lack of these elements can pose a significant barrier to successful transboundary management.

Coordinating institutions can support transboundary cooperation through providing a platform of stakeholder interaction. In Europe, RBOs and sub-basin institutions are common. In some cases, RBOs have been able to push forward their own initiatives, for example on climate change. However, coordinating institutions frequently face a lack of power or legal status that hinders their work.

One of the key supporting aspects of European transboundary management would appear to be the ability to have overarching legal frameworks, provided by the EU, and centralised coordinating institutions at various levels for stakeholder engagement as well as for data sharing and early warning. The European experience also indicates, however, several aspects that should not be overlooked in transboundary management. This includes sectoral integration, participation and CCA. Reorganising management around the river basin has many benefits, but it can also create discrepancies. The large scale of RBDs can pose challenges to achieving effective participation, and in aggregating the work of sub-basin organisations to the basin level. It also has the potential to enlarge gaps between water and other sectors. Greater attention should be given to these aspects of horizontal and vertical integration. Lastly, although there is growing attention for CCA in Europe, coordinated progress appears limited. This may be due to the apparent lack of inclusion for CCA in legal frameworks, as opposed to other issues. More attention for CCA in transboundary regulations and agreements could help to reinforce it. Transboundary arrangements can often take many years to establish, and the relative recentness of these areas could be a contributing factor to lack of progress compared to other aspects.

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A Systematic Literature Review of Community-Based Knowledge in Disaster Risk Reduction

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Abstract Community-based knowledge has protected communities from natural hazards for decades. This knowledge, gathered throughout generations from observation, has increased the capability of people to understand the behaviour patterns of natural hazards specific to their local environment. Many people have used these observations to develop their own sets of defence strategies. Recent disaster risk reduction (DRR) policies have highlighted the importance of community-based knowledge and previous studies have shown the contribution they can make towards productive DRR practices in different context. However, they also show a failure to translate that knowledge into practice. This chapter presents a study to understand the role of community-based knowledge in disaster risk reduction (DRR). It is based on a systematic literature review using academic literature published online after 2010, as well as recent international policy documents related to DRR. The study addresses three guiding questions: What are the definitions and terminology associated with community-based knowledge? How is community-based knowledge addressed within international policies on DRR? What is the contribution of community-based knowledge to current DRR practices? A key word search was carried out using the terms Community-based knowledge, local knowledge, traditional knowledge, indigenous knowledge, disaster management and disaster risk reduction. The literature highlights that recent development activities and DRR measures have considered community-based knowledge as an important factor in sustainable development, yet there is a gap in integrating these measures into practice. Further studies are needed to improve and develop the mechanisms of integration to apply community-based knowledge productively for DRR.

Keywords Local knowledge · Indigenous knowledge · Traditional knowledge · Community-based knowledge · Disaster risk reduction

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1 Introduction

Community-based disaster risk reduction (DRR) has become a focus area among current sustainable development practices. Effective development planning requires a good understanding of the local environment and the risk posed by natural hazards (Dickson et al., 2012). In order to better understand these local environmental conditions, accessing knowledge among the community has been recognised as an important aspect of planning. Typically, DRR measures and development activities were implemented using risk assessments based on expert knowledge. When understanding the environmental functions and processes, both expert and local knowledge are equally important (Retnowati et al., 2014). As a result, there has been increasing recognition of the need for community based knowledge to be incorporated within planning and implementing DRR measures, and wider development activities (Dekens, 2007; Mercer et al., 2010). Despite this, recent studies indicate there are gaps in the adoption of community based practices, which could otherwise help to better understand local environmental conditions and the behaviour of natural hazards in communities (Cadag & Gaillard, 2012; Lebel, 2013).

The most recent international policies and frameworks are also recognising the importance of community-based practices. The Sendai Framework for Disaster Risk Reduction (SFDRR) 2015–2030 highlights how community-based knowledge can support our understanding of small scale and slow-onset disasters in their local environment. It also stresses the need to get the support of local communities in designing and implementing DRR measures. Other international policies and frameworks, including the 2030 Agenda for Sustainable Development, the Paris Agreement on Climate Change and the New Urban Agenda, also highlight the importance of adopting community-based knowledge in their respective domains.

The latest international policies and frameworks have also focused on the importance of including both top-down and bottom-up approaches in planning and implementation processes. Traditionally, planning was done by experts and translated to the community level, following a top-down approach. More recent studies have shown the importance of a bottom up approach to provide a better understanding of the local situation (Bosher, 2014; Mercer et al., 2010; Palliyaguru et al., 2014; Sim et al., 2017). Many of these studies also advocate for a combination of the top-down and bottom-up approaches.

Across different contexts and types of literature and disciplines, a wide range of terminology is used to describe knowledge at the local and community level, including indigenous knowledge, local knowledge and traditional knowledge. Although sometimes used interchangeably there are important distinctions between these terms commonly associated with community-based knowledge.

This chapter seeks to better understand the different terminologies associated with community-based knowledge in the context of DRR. It also examines the extent and how such knowledge is reflected in current policies and practices related to DRR.

2 Methodology

In this chapter, the concepts related to community-based knowledge are explored using a systematic review based on two bodies of literature. The first part of the literature review focuses on four recent international policies and frameworks related to DRR: the Sendai Framework for Disaster Risk Reduction 2015–2030, the 2030 Agenda for Sustainable Development, the New Urban Agenda, and the Paris Agreement on Climate Change. The second part of the literature review is based on academic and scientific studies that have been peer reviewed. The Scopus database was used as the main source for this literature.

Several research questions guide the review:

1. What are the definitions and terminology associated with community-based knowledge?
2. How is community-based knowledge addressed within international policies on DRR?
3. What is the contribution of community-based knowledge to current DRR practices?

Key words	*Related terms*
Community based knowledge	Indigenous knowledge
	Local knowledge
	Traditional knowledge
Disaster risk reduction	Disaster management

Within the literature there are considerable differences in the terminology associated with community-based knowledge. Indigenous knowledge reflects the historical knowledge transmitted through generations, whereas local knowledge may not have a significant historical background but still provide an understanding about local conditions (Purcell, 1998). Traditional knowledge is also explained as the knowledge generated by individuals that comes from their own observation, experience, beliefs and perception (Gupta & Singh, 2011). All these terms are associated with community-based knowledge, which can be used as an umbrella term (Abdullah & Sulaiman, 2013). Therefore, all these terms were used in defining the search string of the literature review. Apart from community-based knowledge, the other key focus of this review is on DRR, which is a significant part of disaster management field. Some literature may have used the broader field of disaster management along with community-based knowledge. Therefore, both terms have been used for the search string of the literature review.

Sources/Digital Data Bases

For academic and scientific papers, the Scopus database was used. 31 research papers were selected for the study using the following search strings and criteria.

Search String

("Community-based Knowledge" OR "Local Knowledge" OR "Indigenous Knowledge" OR "Traditional Knowledge") AND ("Disaster Risk Reduction" OR "Disaster Management").

Inclusion Criteria

- Research papers, book chapters, journal articles are considered
- Should include the term/ terms in the title
- Should be in English
- Should be related to one or more domains of disaster management and indigenous knowledge
- Published after 2015.

Exclusion Criteria

- Reviews, meta-analysis and commentaries were excluded
- Non-English papers were excluded.

3 Results and Discussion

3.1 Definitions of Indigenous and Local Knowledge

For community-based knowledge, there are three main terms highlighted in the literature: traditional, local and indigenous. Traditional knowledge is recognised as the skills and practices which have been developed by communities and passed down through generations, and that are also embedded into their culture and spiritual identity (WIPO, 2017). Local knowledge is referred to as the knowledge developed by communities based on their experience, adapted to their local environment and again tested over centuries of time (UNISDR, 2009). Indigenous knowledge is either formally or informally transmitted knowledge among peer groups through social encounters, oral traditions and ritual practices (Bruchac, 2014). Indigenous knowledge is also considered as a part of broader traditional knowledge (Brush & Pol'y, 2005). However, all these terminologies refer to the community-based knowledge that has been gathered through experience and transmitted among the members of that community. Community-based knowledge is the umbrella term, which can be segmented into three types: indigenous, traditional and local.

The key differences among these three terminologies are the temporal and spatial scale of creation of the knowledge. Both traditional and indigenous knowledge have been transmitted through generations for a longer period of time (Berkes et al., 2000; Gupta & Singh, 2011). However, the difference between traditional and indigenous knowledge relates to the knowledge holders among the community. Traditional knowledge is spread across the broader community, whereas indigenous knowledge is unique to a small native or indigenous community within that broader community (Brush & Pol'y, 2005). Aside from this, they have the same characteristics. In contrast, local knowledge does not necessarily have a long historical background (Dekens, 2007; Kapiarsa & Sariffuddin, 2018; Madhanagopal & Pattanaik, 2019). However, as with traditional and indigenous knowledge, local knowledge can be transmitted through generations and has the potential to transform into traditional or indigenous knowledge in the future.

The common characteristic among local, traditional and indigenous knowledge is that it is gathered through observations and experience (Bruchac, 2014; UNISDR, 2009; WIPO, 2017). Long term observation and personal experience create a unique set of knowledge which is applicable to that particular environment, yet covers micro level aspects related to any phenomenon. It supports a deep understanding about the local environmental conditions, which could relate to and inform DRR as well as development planning (Raymond et al., 2010). As a result, some planners and decision makers are adopting community-based knowledge to solve more complex environmental problems, including natural hazards (Bohensky & Maru, 2011).

A common theme explored within the literature is how community-based knowledge contrasts with scientific knowledge. Community-based knowledge is considered to be tacit knowledge which is based on personal experience (Semeon et al., 2015; Stilwell, 2010). It is the knowledge generated by communities and tested over generations of time, which becomes part of the culture (UNISDR, 2009; WIPO, 2017). Scientific knowledge is explicit knowledge, using empirical practices based on data, scientific formulae, universal principles, and so forth (Edvinsson & Malone, 1997). Anyone can test out scientific knowledge based on the methodologies used and new knowledge can be created based on experimentation (Carey & Smith, 1993). It is most commonly transmitted as a written form of knowledge. In contrast, community based knowledge has no empirical basis and is transmitted verbally through the communities (Renzaho et al., 2007). However, researchers have highlighted the importance of translating community based knowledge into practice with the support of a scientific basis (Jull et al., 2017).

In relation to disaster risk, indigenous and local knowledge are frequently associated with an understanding of local environmental conditions. Community-based knowledge is recognised as knowledge of the environment which passes down through generations (Agrawal & Change, 1995) and it has the ability to interpret small scale functions of the environment which may be essential in development planning. For example, community-based knowledge has shaped human interaction with their local environment (Dube & Munsaka, 2018) where people in those communities develop their own set of mechanisms to deal with environmental issues. This knowledge on adaptive mechanisms and local environment can support DRR as well as development activities in a productive manner but seems especially suited to a small scale. For example, it has been reported that small scale development projects have a higher success rate if integrated with community-based practices (Amadei, 2014). Community-based knowledge is a complicated system yet has the potential to be contribute to a more complete understanding of the local environment, which is also dynamic in nature and practical in use after being scientifically validated (Bates, 2009; Battiste, 2002). Therefore, it is a productive input for understanding the local environmental conditions for DRR and development activities in the planning stage.

3.2 Community-Based Knowledge and International Policies

International policies related to DRR have evolved through decades, starting from the Stockholm Declaration in 1972, the Natural Disasters and Vulnerability Analysis in 1979, the UN Framework Convention on Climate Change in 1992 and Vancouver Declaration in 1976. This chapter considers four recent policy and framework documents related to DRR, which have evolved from these. Each policy has considered the importance of indigenous and local knowledge in DRR practices. A synthesis of these concepts is illustrated in Figs. 1, 2, 3 and 4.

The SFDRR uses all three terminologies to illustrate community-based knowledge: traditional, local and indigenous knowledge. As illustrated by Fig. 1, they are related to several different aspects of DRR. A prominent aspect is risk identification. In common with the scientific literature, it recognises its role in understanding the local environment in order to identify the risk accurately. The SFDRR has given provision to incorporate community-based knowledge into decision making. It recognises the importance of local communities in the planning process of decision making. However, these ideas seem important in the planning stage, rather than changing them later based on the environmental conditions of a given area. Incorporation of community-based knowledge at the planning level will strengthen a risk informed decision-making process.

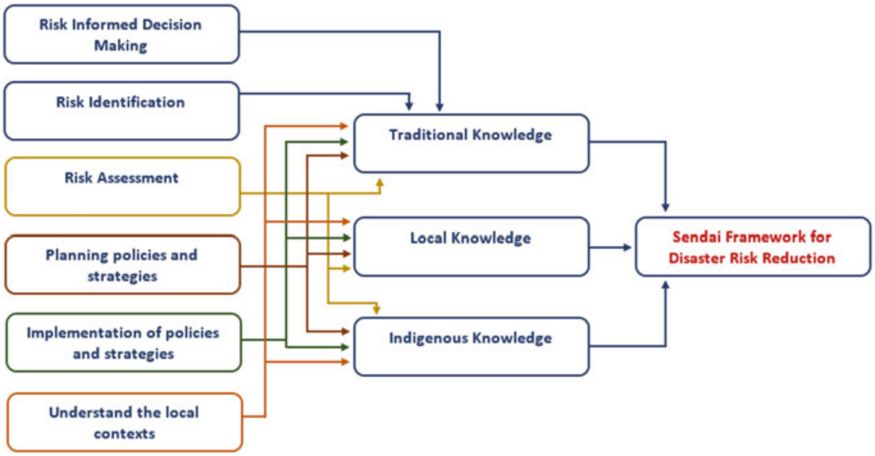

Fig. 1 Conceptual background of SFDRR and links to community-based knowledge

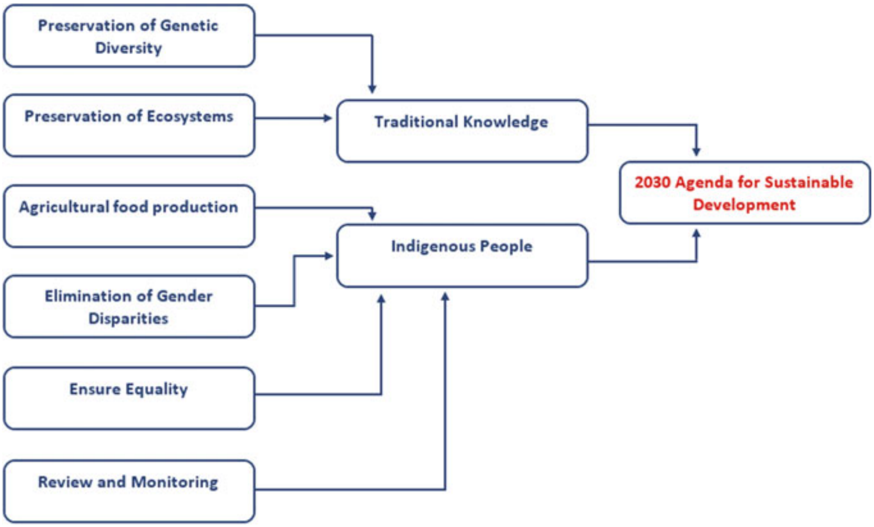

Fig. 2 Conceptual background of 2030 agenda for sustainable development on community-based knowledge

Fig.3 Conceptual background of Paris agreement on community-based knowledge

As highlighted in section D under guiding principles, the importance of traditional knowledge in decision making, alongside scientific approaches, is clearly illustrated. It has used the term traditional knowledge to highlight one component of community-based knowledge.

> Disaster risk reduction requires a multi-hazard approach and inclusive risk-informed decision-making based on the open exchange and dissemination of disaggregated data, including by sex, age and disability, as well as on easily accessible, up-to-date, comprehensible, science-based, non-sensitive risk information, complemented by traditional knowledge. (UNDRR, 2015, p. 13)

It stresses the need for a multi-hazard approach in decision making, where traditional knowledge can provide information about all hazardous events within their

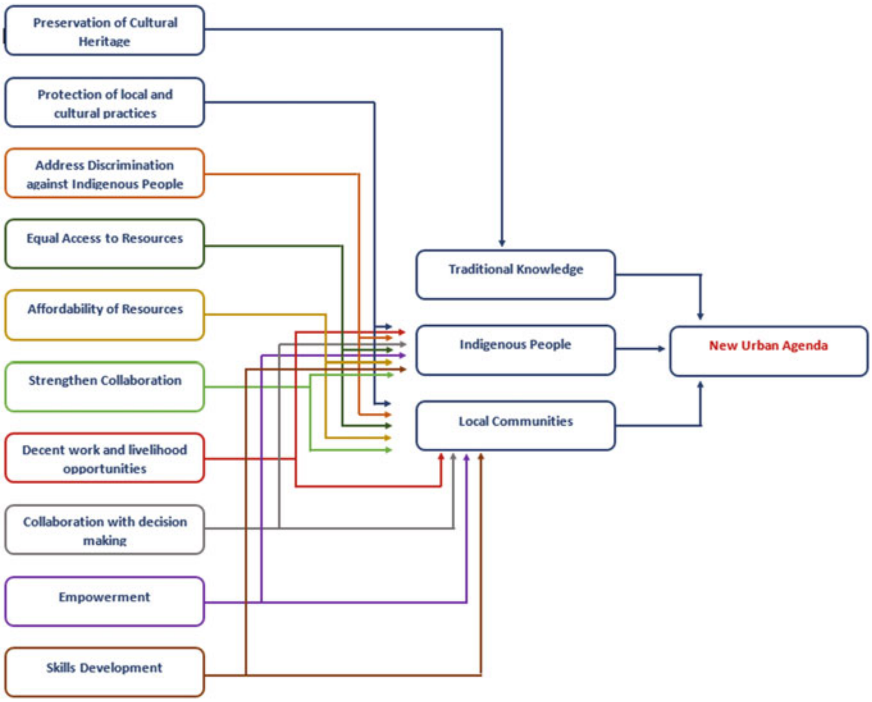

Fig. 4 Conceptual background of New Urban agenda on community-based knowledge

spatial context. The SFDRR also emphasises the need for community-based knowledge to be easily accessible and also up to date. It is one productive contributor of decision making based on an open exchange and dissemination of disaggregated data.

SFDRR has given provision to incorporate all three components of community-based knowledge in disaster risk assessment:

> To ensure the use of traditional, indigenous and local knowledge and practices, as appropriate, to complement scientific knowledge in disaster risk assessment and the development and implementation of policies, strategies, plans and programmes of specific sectors, with a cross-sectoral approach, which should be tailored to localities and to the context. (UNDRR, 2015, p. 15)

It can be used, along with scientific knowledge, to extract micro level information. It can also be used as a mechanism to validate the outputs of scientific knowledge. If there are discrepancies between them, it provides a basis for further investigation. Along with assessment of disaster risk, the SFDRR also promotes the use of community-based knowledge for implementation of DRR measures and development of policies. This idea is reinforced in sections IV, V and VI under the section on role of stakeholders in SFDRR.

SFDRR can strengthen community participation in all levels, including decision making, which gives communities some authority and a sense of ownership of the activities being implemented. It also has the possibility of utilising the same knowledge and inputs along with monitoring and evaluation activities based on the authority and the sense of ownership that communities have. Moreover, the provision given by SFDRR for disaster risk reduction has the capacity to strengthen the productivity of DRR practices through community engagement using their knowledge on the environment and natural hazards.

The 2030 Agenda for Sustainable Development uses the term traditional knowledge to highlight the knowledge obtained from local communities. However, there is no direct reference to DRR. As highlighted by the quote from goal 2.5, the term is used in the areas of preservation of genetic diversity and ecosystem protection.

> By 2020, maintain the genetic diversity of seeds, cultivated plants and farmed and domesticated animals and their related wild species, including through soundly managed and diversified seed and plant banks at the national, regional and international levels, and promote access to and fair and equitable sharing of benefits arising from the utilization of genetic resources and associated traditional knowledge, as internationally agreed. (UN, 2015, p. 15)

However, ecosystem protection is linked with disaster risk reduction under current ecosystem-based approaches. The current practices of DRR have recognised the areas of green infrastructure, ecosystem based adaptation and eco-DRR as productive and sustainable implications (Depietri & McPhearson, 2017; Onuma & Tsuge, 2018; Renaud et al., 2016). Therefore, the potential of incorporating community-based knowledge can be identified under this component for DRR.

The term indigenous people is used in several sections, including paragraph 23, 25, 52, 79, goal 2.3 and goal 4.5. Under goal 4, the term of traditional people is used to discuss education when eliminating gender disparities. Apart from the focus on ensuring inclusive and equitable quality education, there is no mention about DRR or ecosystem-based adaptation within this goal.

> By 2030, eliminate gender disparities in education and ensure equal access to all levels of education and vocational training for the vulnerable, including persons with disabilities, indigenous peoples and children in vulnerable situations. (UN, 2015, p. 17)

The 2030 Agenda for Sustainable Development emphasises the areas of agricultural food production, gender disparities, equity and involvement of indigenous people for monitoring and progress review. Again, there is no direct reference to indigenous or local knowledge with DRR. However, the need for convergence between the SFDRR along with other international frameworks and policies like the Paris Agreement on Climate Change and the 2030 Agenda for Sustainable Development is widely recognised (Kelman, 2017). Others have highlighted the potential of incorporating DRR aspects into almost every goal (Izumi et al., 2020; Schipper et al., 2016; Seidler et al., 2018).

The Paris Agreement is mainly focused on prevention of greenhouse gas emissions in order to prevent climate change. As highlighted in article 07, it has used the terms local, indigenous and traditional knowledge in relation to developing adaptation actions for climate change.

> Parties acknowledge that adaptation action should follow a country-driven, gender-responsive, participatory and fully transparent approach, taking into consideration vulnerable groups, communities and ecosystems, and should be based on and guided by the best available science and, as appropriate, traditional knowledge, knowledge of indigenous peoples and local knowledge systems, with a view to integrating adaptation into relevant socioeconomic and environmental policies and actions, where appropriate. (UNFCCC, 2015, p. 9)

It emphasises the connection between vulnerable groups, communities and ecosystems for climate change mitigation, guided by indigenous people, traditional and local knowledge. Therefore, the Paris Agreement has given provision to extract that knowledge and develop adaptation actions for climate change. Currently, many ecosystem-based approaches for climate change are focused on using community-based knowledge for ecosystem resilience. In a similar vein, the Paris Agreement also has provision to incorporate community-based knowledge into climate change mitigation, which is directly linked with DRR.

The New Urban Agenda also addresses traditional knowledge to some degree, but again, not directly related to DRR. It highlights the use of traditional knowledge for the preservation of cultural heritage in paragraph 125.

> We will engage indigenous peoples and local communities in the promotion and dissemination of knowledge of tangible and intangible cultural heritage and protection of traditional expressions and languages, including through the use of new technologies and techniques. (UN Habitat, 2016, p. 32)

In other perspectives, local communities and indigenous people are addressed in paragraphs 20, 34, 38, 42, 48, 57, 125, 134, 148, and 155, each focused on a different part of the development process. As highlighted by Fig. 4, they are related to socio-cultural aspects rather than DRR. However, as with the 2030 Agenda for Sustainable Development, the New Urban Agenda recognises the importance of community-based knowledge in development practices. However, it has not clearly illustrated the link between DRR and community-based knowledge, or how it can be incorporated for sustainable development through DRR.

Based on the reviewed policies, there is a strong provision given within the SFDRR and the Paris Agreement to incorporate local and indigenous knowledge with DRR activities. The 2030 Agenda for Sustainable Development and the New Urban Agenda also recognise the importance of indigenous and local knowledge, as well as disaster risk reduction, but in separate sections. The link between them is not explicit.

3.3 Contribution of Community-Based Knowledge to DRR

From current practices there is evidence of where community-based knowledge has been used in DRR activities to better understand the situation (Gero et al., 2011; Nakamura et al., 2017; Niekerk et al., 2018). Normally, community-based knowledge is limited to a small part of a major region but these communities have expertise on a specific natural hazard (Mercer et al., 2010). Moreover, they may be experts about the behaviour and the characteristics of that particular natural hazard based on the local environmental conditions (Corburn, 2003). This community-based knowledge has the capacity to understand the behaviours and characteristics of natural hazards, and in some situations, this appears to have been just as, or even more effective than expert knowledge. For example, coastal fisherman communities have been shown to have knowledge on wind patterns, erosion and even fishing sites and shore line conditions by monitoring their local environmental conditions (Madhanagopal & Pattanaik, 2019). Also some inland farming communities have the ability to predict landslides by observing changes in local environment (Aditya et al., 2020). This knowledge has supported these local communities to survive against various natural hazards throughout the time. However, the application of this knowledge is limited to small communities.

Local communities have the gathered knowledge through long term observation about the behaviour of the natural hazards within their local environmental conditions (Jull et al., 2017; Kapiarsa & Sariffuddin, 2018). This knowledge is important in identifying the risk or making the risk assessment for the area. However, the assessed risk will only be applicable for that particular local community, but with the potential for a high degree of accuracy and specificity. Accurate mechanisms of risk identification can lead to risk informed decision making, not only for DRR, but also for development practices as well (Amendola, 2002; Papazoglou et al., 2000). Local people have the knowledge to explain micro level scenarios related to natural hazards, which are sometimes very important at the planning level. They also sometimes have potential solutions that can be used in practice but may not have been scientifically tested. These practices may have helped communities to reduce the harm caused to them by natural hazards (Kapiarsa & Sariffuddin, 2018; Lin & Chang, 2020; Renzaho et al., 2007).

Numerous studies have suggested that community-based knowledge has strengthened resilience in local communities. Throughout generations they have practiced and developed this knowledge related to DRR, which current DRR practices have also tried to adopt (Hiwasaki et al., 2014; Weichselgartner & Pigeon, 2015). Sometimes the community-based knowledge may appear as beliefs and rituals, yet they act as disaster prevention and preparedness mechanisms (Fadli & Masnun, 2020). Many local communities have their own practices to protect from natural hazards. The snail and chameleon egg hatch observation for predicting droughts and inland migration of hippopotamuses before a flood event are some of the practices used by African local communities (Macnight Ngwese et al., 2018). Local farmers in hill areas knew how to use land without disrupting the environmental processes as well as the mechanisms for preventing soil erosion and potential landslides (Aditya et al., 2020). Therefore, local communities were able to make their communities more resilient through the knowledge gathered by themselves over a long period of time.

When implementing DRR measures, many local communities still trust local measures that have been passed down generations (Jha & Jha, 2011; Morrison, 2017). Expert knowledge on DRR focuses more on a holistic approach where the practices can be applied to many parts of the world, depending on primary environmental conditions like climate, soil and precipitation (Palliyaguru et al., 2014). Therefore, these may not address the micro impacts from natural hazards where local communities had their own way to handle those issues (Macnight Ngwese et al., 2018; Wisner, 2009). As a result, some people have tended to trust local, traditional and indigenous knowledge more than the expert solutions for disaster mitigation and risk reduction (Balay et al., 2018). Also due to the lack of resources and technologies, the capacity to implement expert solutions may not be sufficient (Macnight Ngwese et al., 2018). These examples suggest a need to integrate local and indigenous knowledge with current DRR policies.

Most of these community-based practices are based on nature, and do not require high-tech equipment for forecasting the events or preparedness. Generations of observations have developed set of norms in the local communities regarding disaster prevention, where they have been adopted in day to day life. As an example, tribal communities in Taiwan use long-term changes in topography, hydrology, flora, and fauna as premonitory symptoms of debris flow, typhoon floods, and earthquakes (Lin & Chang, 2020). There are many African countries which use observation and skilful analysis of atmospheric variables and biological features as a tool of weather forecasting (Iticha & Husen, 2019). Many of these local practices seem to work well within their local communities and provide low costs, sustainable, nature-based solutions.

Community-based knowledge would appear to be applicable in all sectors of disaster forecasting, preparedness and implementation. It is used in many fields that support building resilient communities, including construction, agriculture and DRR. In farming or agricultural practices, indigenous knowledge has been used to sustain their crops from droughts, preservation of seeds and also as a mechanism for forecasting droughts (Muyambo et al., 2017). It was also used for sustainable or disaster resistant housing construction in many parts of the world, like the earthquake-resistant design of “Sasak” house construction in Indonesia (Fadli & Masnun, 2020).

Community-based knowledge is used in all stages of disaster management, including pre, during and post disaster related activities. Pre-disaster, it has been used as an early warning mechanism to predict natural hazards based on the environmental changes before they happen (Lin & Chang, 2020; Pareek & Trivedi, 2011). It has also been successfully integrated with evacuation, monitoring and dissemination of warnings among communities during a hazard event (Šakić Trogrlić et al., 2019). In post disaster perspectives, community-based knowledge has been integrated with disaster recovery through build back better (Mavhura et al., 2013) and in disaster recovery through the tourism industry (Kato, 2018) and settlement planning (Miller, 2019).

Though it is recognised as important in the literature, there a is lack of community based knowledge incorporated with DRR practices (Cuaton & Su, 2020). However the literature also highlights how important it is to integrate these knowledge categories with DRR in order to obtain more promising results with disaster mitigation (Balay-As et al., 2018; Lambert & Scott, 2019; Syahputra, 2019; Wang et al., 2019).

Some countries like Indonesia has a strong basis for utilising community based knowledge in DRR (Hutagalung & Indrajat, 2020), yet a balance of both expert and local knowledge will provide more sustainable solutions for DRR activities (Birkmann & Teichman, 2010; Cadag & Gaillard, 2012; Gaillard & Mercer, 2013).

3.4 Challenges for Using Community-Based Knowledge in DRR

One of the major challenges related to indigenous and local knowledge is that the knowledge itself is degrading in modern generations (Reyes-García et al., 2013). Modern generations have more advanced technologies for obtaining information related to natural hazards, reducing their need to make use of or rely on traditional knowledge (Santos & Aguirre, 2007; Thomas, 2018). As an example, studies of fishing communities in Tamilnadu, India have revealed that senior fishermen had the knowledge to understand their coast and shore lines through the observation, but the current generation seem to be less interested in traditional methods (Madhanagopal & Pattanaik, 2019). The studies found that knowledge seems to be decaying though generations and younger generations are losing their trust in traditional knowledge (Madhanagopal & Pattanaik, 2019).

Within community-based knowledge there are three knowledge categories: common knowledge, shared knowledge and specialised knowledge (Kapiarsa & Sariffuddin, 2018). The most important category is specialised knowledge and it is not easily accessible with in the local communities (Šakić Trogrlić et al., 2019). Specialised knowledge under community-based knowledge in DRR refers to the gained understanding about a particular disastrous situation and its behaviour within a local environmental setting (Weichselgartner & Pigeon, 2015). It provides specific information about the disaster and its behaviour for risk reduction and mitigation activities of the area. In modern society, specialised knowledge seems to decay and only elderly communities have such knowledge practices. In some cases, even elderly communities may no longer practice such knowledge due to the changes in their economic activities and lifestyle (Tang & Gavin, 2016).

Another challenge is that community based knowledge is not equally distributed among communities (Hutagalung & Indrajat, 2020). For example, the traditional or local flood risk reduction strategies may vary from one community to another based on the local environmental conditions, yet provide promising results for that particular community. For instance, flood early warning based on the behaviour of the hippopotamus is unique to African communities (Mbukusa, 2015), yet effective for their community resilience. Therefore, it cannot be neglected and disregarded. A better scientific understanding of how it works, improved monitoring and a mechanism for integration may increase the usability of such knowledge in other parts.

The local, traditional and indigenous knowledge is based on long-term observations and the interpretations of the members of the community. Due to this, practitioners claim that it is not properly documented and cannot be scientifically validated (Dube & Munsaka, 2018). They also highlight that it is not equally transmitted through the generations and there are generational gaps as well as different interpretations in different communities. However, based on available resources and experience, people have gathered this knowledge, which has also supported them with long-term survival from natural hazards. Therefore, it would seem to be a missed opportunity if these societies now neglect it. However, it will be important to build a formal mechanism for integrating this knowledge into practice, or even for scientific validation.

4 Conclusion

The results of this review suggest that there should be a proper integration of community-based knowledge with DRR practices. For many years and for generations prior to the establishment of modern institutions and frameworks, local communities were able to sustain their lifestyles while adapting and reducing the impact from natural hazards.

However, modern institutes, frameworks and policies have strengthened DRR activities and provided a global and national platform to address disaster risk. These frameworks and policies do recognise the importance of integrating community-based knowledge with DRR in order to strengthen the decision-making process and also increase the success rate of DRR interventions.

When integrating community-based knowledge with DRR, the community has to play a vital role. It is important to strengthen community participation in all aspects of DRR activities in order to achieve a successful outcome. Local communities can support risk reduction before a hazard strikes, for example by contributing for early warning and forecasting using community-based knowledge. They can also contribute towards mitigation measures using community-based knowledge, for example, in how to construct a disaster resistant house, identifying resilient agricultural practices and sustainable use of land. Small groups from the community can contribute for evacuation, monitoring and dissemination of warnings during a hazard event. Community-based post disaster strategies have been found to be more effective when it comes to sustainability. Therefore, integrating community participation, even for the decision-making level, can result in better outcomes for DRR practices.

Education and awareness on DRR should be strengthened with community-based knowledge and applications to make those DRR measures fruitful. One of the major issues is the decay of indigenous and local knowledge among upcoming generations. Education can help to preserve the local and indigenous knowledge while contributing towards DRR activities. For example, indigenous knowledge banks have been suggested as a measure of preservation (Iticha & Husen, 2019). This type of initiative can make the knowledge available for many stakeholders and researchers, who then can create new knowledge and practices based on the existing knowledge related to DRR.

Community-based knowledge would appear to have supported the development of more resilient communities even before the adoption of current DRR practices. Communities had their own way of facing, mitigating and preparing mechanisms for natural hazards. However, climate change and other development trends, such as population growth, have intensified the frequencies and impacts from natural hazards, creating new challenges for these established and community-based DRR practices. The post-2015 development frameworks have laid a strong foundation for DRR to address these greater threats but also recognise the importance of community-based knowledge and their applicability in DRR related activities. However, a review of recent studies suggests that better mechanisms are required to integrate community-based and expert knowledge. Global policies and frameworks have given provision to incorporate these knowledge components along with ecosystem-based approaches to DRR. If practitioners and relevant stakeholders can provide the necessary legislative and institutional framework to integrate community-based knowledge, DRR applications can be more sustainable.

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Flood Risk of Porathivu Pattu in Batticaloa District, Sri Lanka

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Abstract The Batticaloa District is one of the flood-prone areas in Sri Lanka. It creates an impact on the agriculture sector, disturbs the habitual life and makes people live vulnerable. This study examined the flood hazard and then introduced the flood risk area for the Porathivu Pattu. Two River basins namely Andella and Navagiri have been selected to examine the flood risk (FR). The parameters which are the most important factors influence flood hazard in the study area like, distance from the River, soil type, land use type, and elevation have been considered in flood hazard and risk analysis. Flood Hazard Map (FHM) has been created using a weighted overlay analysis method in ARC-GIS 10.3 software. The flood risk areas have been introduced based on the FHM. The FR has been classified into five categories, namely Very Low Risk, Low Risk, Moderate Risk, High Risk (HR) and Very High Risk (VHR) with the area coverage. This study also examined the effect of floods on paddy cultivation and home gardens based on the FHMs. The Paddy Land (PL) (87% of PL in VHR and 90% of PL in HR) and Home Gardens (HG) (08% of HG in HR) have been identified within the VHR and HR areas. The study suggested to improve the structural and non-structural strategies more effectively in Porathivu Pattu.

Keywords Flood · Risk · Vulnerability · Agriculture

1 Introduction

The flood is the most common and widespread of all-natural disasters in the world. Similar to other countries across the globe, Sri Lanka also experiences a flood disaster as a result of an extreme weather event due to global climate change. The climate in Sri Lanka is considered as the tropical monsoonal and consists of very distinctive dry

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and wet seasons. The Sri Lanka has four climate seasons i.e., First inter-monsoon season (March–April), Southwest monsoon season (May–September), Second inter-monsoon season (October–November), and Northeast monsoon season (December–February) (Thadshayini et al., 2020). With respect to the rainfall, Sri Lanka has been divided into three main climatic zones, namely wet zone, intermediate zone, and dry zone. The boundaries of these three zones have been demarcated with consideration of present agricultural land use, distribution of forest species, rainfall, topography, and soils (Nianthi, 2012).

The districts of Kegalle, Ratnapura, Kalutara, Colombo, Gampaha and Galle are subject to flooding on account of Southwest monsoon rains, while Ampara, Trincomalee, Badulla, Polonnaruwa, Batticaloa, Matale and Monaragala suffer from the Northeast rains (Country Report Sri Lanka, 2003). The sectoral distribution of the country for GDP i.e. agriculture (primary) industry (secondary) and services (tertiary) are seriously affecting, when the magnitude of flood is high in these districts. Since the last few decades, the country has been experiencing significant changes in the climate system, especially including drastic variations in monsoonal rain patterns (Malmgren et al., 2003), long-term drought conditions, and unexpected flooding conditions that are severely affecting the agricultural production in the country (Thadshayini et al., 2020).

Most of the economic losses were recorded in the low-lying areas of the Northern region of Sri Lanka due to flood. The highest amount of housing damages and commercial sector losses were caused by the flood, during the Northeast monsoon season and Second inter-monsoon season (Rajendram, 2014). The community of this area had been affected by flood either directly or indirectly. The northeast monsoon seasons the eastern side of the country is prone to flooding. Batticaloa District is one of the flood prone areas in the eastern side of Sri Lanka. It lies within the flood damage risk zone in the country. In 2011 there was a severe flood experience in the area which created enormous damage to the agriculture sector and its community. It was estimated that economic lost by 2011 flood is around 4540.22 million Sri Lankan Rupees in Batticaloa District (Flood affected report, Batticaloa, 2011). Heavy rains from 16 to 24 December 2007 resulted in progressively larger numbers of affected and displaced people. During the first two days of the rains, the main affected areas were limited in the central region of the Batticaloa District. Continued heavy rains from 23 to 24 December caused a significant increase and spread from the Northern tip of Batticaloa District down along to the coastline. The population of the affected districts was around 250,000, which included more than 40,255 displaced in 37 welfare centers and schools. A break in the rains after 24 December resulted in the return of the majority of families, with only 252 individuals remaining displaced by 27 December (Sri Lanka: Batticaloa Flood OCHA Situation Report, 2007).

For recent years, in applications, of Geographical Information System (GIS) has proved to have simultaneous practical value, providing information for decision makers, and theoretical value, helping to understand human environment interaction. GIS is providing some provision to prepare the hazard, disaster and risk mapping using various models for the flood affected areas. Ajith (2008) has examined flood hazard impacts (mapping) in the lower reach of Kelani River. He has examined the flood effected period within every 10, 20, 50 years using flood disaster maps through Terrain Model, Hydrodynamic Model: HEC RAS, TIN Model. Suthakaran et al. (2018) studied the possibility of assessing flood risk and resilience in the coastal areas of the Eastern Province of Sri Lanka through community-based participatory approach and OpenStreetMap (OSM) technologies in Manmunai North Divisional Secretariat of Batticaloa, Sri Lanka.

It is revealed that the community of the Porathivu Pattu DSD has been facing many problems and challenges from the flood disaster every year. This particular area has no any hazard or risk maps for the flood disaster. The flood hazard and risk maps provide important information to help people understand the risks of floods and to help mitigate disasters. Therefore, this study aims to introduce the flood hazard and risk maps for the Porathivu Pattu. The flood risk map of paddy lands and home gardens are also created for the Porathivu Pattu DSD. The flood hazard maps indicate the extent of expected flood risk areas, and can be shared with disaster management information such as evacuation sites, evacuation routes, etc. The maps will be very useful for the researchers, academics and relevant stakeholders as the base maps for their future studies.

2 Study Area

Porathivu Pattu is one of the Divisional Secretariats out of the 14 Divisional Secretariats of Batticaloa District. It has been situated in the Southern direction of Batticaloa District and within 04 km distance from Batticaloa town. It has an extent of 164.7 Sq.km and it covers 6% of the lands of Batticaloa District (Fig. 1). The major part of the land of Porativu Pattu DSD is covered by the paddy to the extent of 11,032 Hectares. It is 67% of the DSD.

3 Materials and Methods

Four main parameters, i.e. elevation, distance away from the River, land-use pattern and existing soil types have been selected for the identification of flood hazard areas based on the reports of Provincial Irrigation Department and Disaster Management Center at Batticaloa, As the study area is small, rainfall has excluded assuming that the rainfall uniformly distributes in the study area. The ranks have been allocated to each parameter considering their influences on creating flood hazard areas. After consulting the Irrigation Engineer of the study region and considering standard ranking system, ranks have been assigned for each parameter based on different conditions and also weightages are assigned for each parameter based on their influence on creating floods.

By considering the above criteria and based on the relative importance of different conditions within each factor, ranks from 1 to 9 are assigned for different conditions

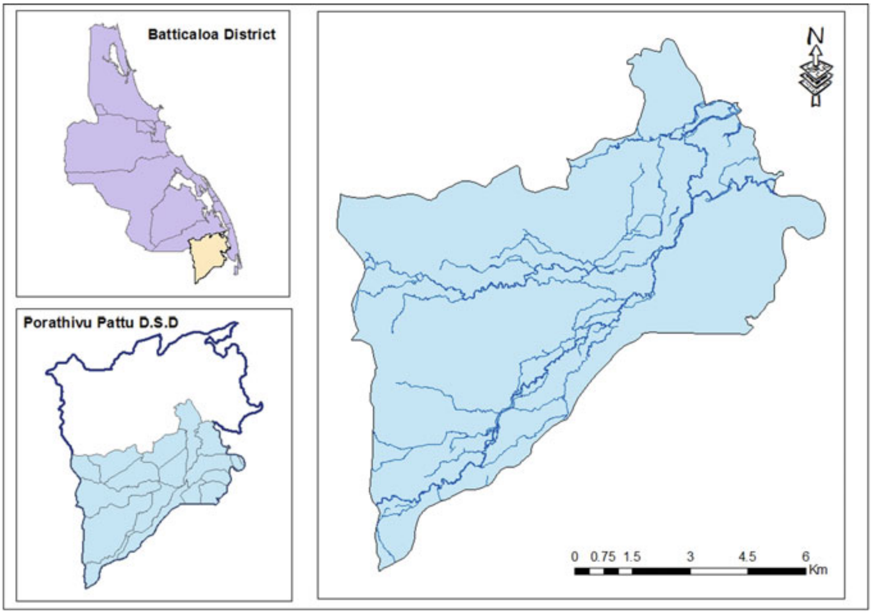

Fig. 1 Study area, porathivu pattu

within factors and will explain under the results and discussion sub title. However, all ranks from 1 to 9 are not included in all parameters. The main reason for such observation is that the missing ranks of parameters indicate that those conditions of parameters are similarly influence to create flood events and therefore, those conditions are not effect for the analysis. Therefore, similar conditions within same parameter are merged and same ranks of matching conditions are assigned. Therefore, ranks 7, 5, 3 and 1, ranks 8. 6. 5 and 4, ranks 7, 5 and 3 and ranks 9, 7, 5, 2 and 1 are missing in river buffer, elevation, land use and soil respectively.

4 Results and Discussion

Preparation of Flood Hazard Map of Porathivu Pattu DSD

The weightage has been assigned for each parameter based on Analytic Hierarchy Process (Staaty, 1988). According to this process, each parameter has assigned weights using Pairwise Comparison Matrix. Impact (Table 1).

River Buffer

Effect on the River is classified into six classes based on the distance away from the River and the impacts of these classes on creating a flood hazard. Ranks were allocated to each class based on their influences on creating flood as shown in below (consulted

Table 1 Weightage assigned for parameters

Parameters	Weight
River buffer	35
Elevation	25
Land-use	20
Soil	20

the experts at the Department of Provincial Irrigation and Disaster Management Center of Batticaloa) (Table 2).

According to the ranks assigned for the distance away from the River, six buffer zones have been introduced for the Navagiri River and Andella River basins in the study area.

Elevation

The range of the elevation of the study area varies from 0 to 35 m. According to the elevation, the study area has been classed into five intervals to verify the flood hazard based on the height. Each class has assigned ranks, considering the effect of elevation on flood hazard. The impact of different elevation levels of flood hazard is given in the Table 3 based on the ranks. An elevation map for the study area has been introduced.

Land Use

The study area has nine types of land uses. Based on these land use types, the study area has been classified into nine classes and assigned ranks to verify the flood hazard based on their influences. The impact of different land-use types on flood hazard is given in the Table 4 based on the ranks. The Land-use map for the study area has been created.

Soil

Totally thirty-eight soil samples have been collected from various places in the study area of Porathivu Pattu with an approximate distance of 2 km to each soil sample point. Global Position System (GPS) of coordinates of each sample point has recorded. All soil samples were tested in the laboratory (Department of Geography,

Table 2 Ranks assigned for distance from the river

Distance (m)	<100	100–200	200–300	300–400	400–500	400–500
Rank	9	8	6	4	2	1

Table 3 Ranks assigned for elevation

Elevation (m)	<1	1–2	2–5	5–10	>10
Rank	9	7	3	2	1

Table 4 Ranks assigned for land-use types

Land-use type	Rank
Water	9
Paddy	8
Homesteads	6
Marshy land	4
Grass land	2
Scrub land, Barren land, forest, other	1

University of Peradeniya) to understand the textural and permeability characteristics of each soil sample. After determining the textural and permeability characteristics, four soil types were identified. Therefore, the study area has been classified into four classes based on the different soil types to verify the influence of soil on flood hazard areas. The impact of different soil types on flood hazard is given in the Table 5 and based on the ranks; soil map of the study area has been introduced.

The flood hazard map has been created using the weighted overlay analysis based on the above weightages. The flood risk of the Porathivu Pattu DSD has been classified into five categories, namely very low hazardous, low hazardous, moderate hazardous, high hazardous and very high hazardous. Accordingly, the entire extent of the study area i.e. 76 sq.km, has differentiate into different hazardous areas and percentages (%) of each hazardous area have also been calculated (Table 6 and Fig. 2).

According to this calculation, 8% of the entire extent is belongings to the very high hazardous area. At the same time about 30% of the extent is having high hazardous. The large area of the extents is covered by the high hazardous area. The Moderate hazardous area was covered by the 17% of the study area of Porathivu Pattu DSD. The Low hazardous area was about 18% and the very low hazardous area was 26%.

Table 5 Ranks assigned for soil types

Soil type	Rank
Fine sand	8
Fine to medium sand	6
Medium sand	4
Medium to coarse sand	3

Table 6 Extend of flood hazardous area of Porathivu pattu DSD

Flood hazardous level	Total extend (sq. km)	Percentage (%)
Very high	06	08
High	23	30
Moderate	13	17
Low	14	18
Very low	20	26

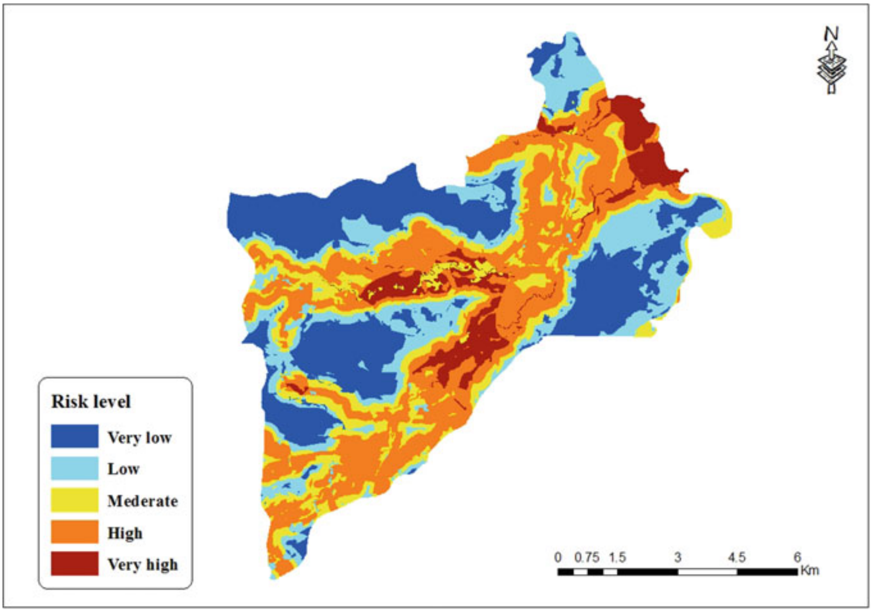

Fig. 2 Flood hazard map of the Porathivu pattu DSD

Flood Risk on Paddy Lands of Porathivu Pattu DSD

Based on the introduced Flood Hazard Map, the risk areas of floods on paddy lands have been verified. The total extent of the very high flood risk area was about 06 sq.km (8%). Out of very high flood risk area paddy lands cover more than 87%. Thus, the paddy lands in Porathivu Pattu DSD have very high risk as shown Fig. 3a. The total extent of the high flood risk area was about 23 sq.km (30%). More than 90% out of the high flood risk area was covered with paddy lands. Therefore, the paddy lands can be considered as high flood risk lands Fig. 3b. The total extent of the moderate risk area was 13 sq.km. Out of this 62% was covered with paddy lands as illustrated in the Fig. 3c. About 77% of the lands (14 sq.km) were identified as low risk areas Fig. 3d. The total extent of very low flood risk area was 20 Sq.km and out of this 45% are paddy land as shown in Fig. 3e.

Flood Risk on Home Gardens of Porathivu Pattu DSD

Out of the total extent of the high-risk area i.e., 06 sq.km, (1%) is covered with home gardens. A home garden with very high flood risk in the study area is illustrated in the Fig. 4a. The total extent of the high flood risk area is about 23 sq.km. Out of this high flood risk areas, around 08% is covered with home gardens. Figure 4b.

The total extent of the moderate flood risk area is about 13 sq.km. About 15% of this high flood risk area is covered with home gardens. Therefore, about 15% of the home gardens in the study area have moderate flood risk (Fig. 4c). The total extent of low flood risk area was 14 sq.km in which 14% is covered with home gardens.

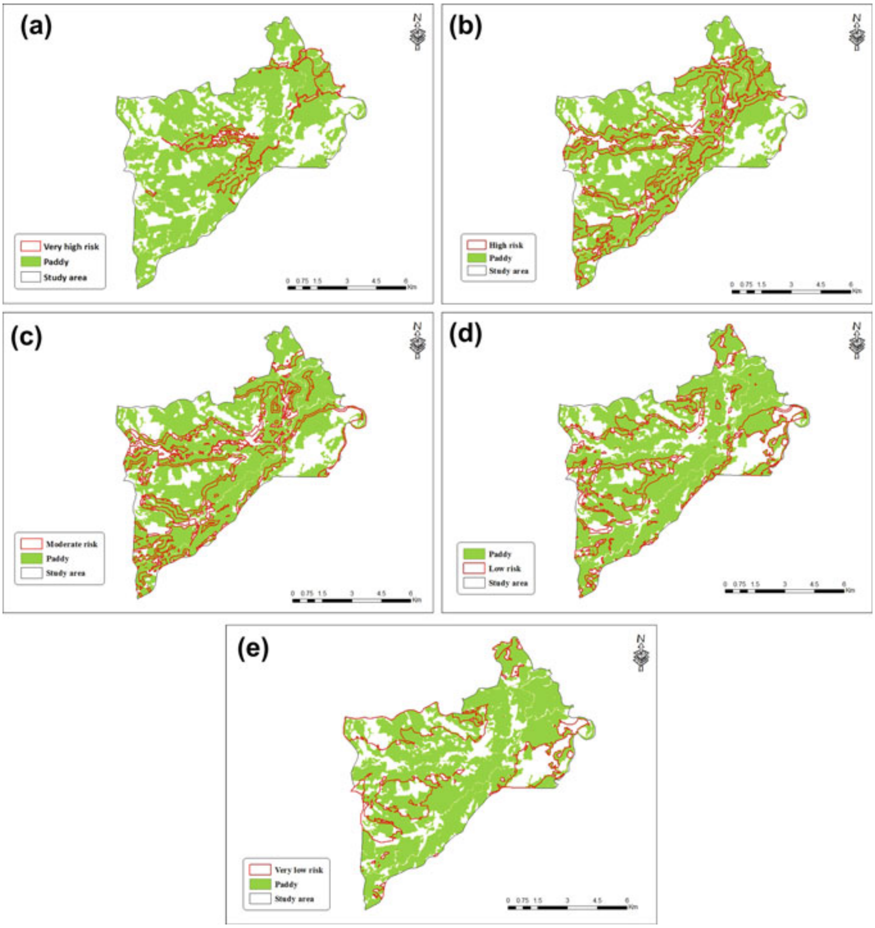

Fig. 3 Paddy lands with **a** very high flood risk, **b** high flood risk, **c** moderate flood risk, **d** low risk **e** very low risk

(Fig. 4d). The total extent of the very low flood-risk area was about 20 sq.km. It was about 46% (Fig. 4e). The Table 7 expresses the different flood risk levels effect on home gardens in the study area of Porathivu Pattu **DSD**.

Therefore, the paddy lands (06 sq.km–87% of paddy lands) and home gardens (06 sq.km–01% of home gardens) have been situated within the very high risk area and high risk area (23 sq.km–90% of paddy lands), (23 sq.km–08% of home gardens). These areas will have the high impacts of flood in future too.

Validation of Created Flood Risk Map

The created flood risk map was validated using Disaster Management Center flood analysis data. This task was completed using Eastern Province, 2014 December flood analysis data of DMC. According to the Satellite-based flood analysis, DMC was

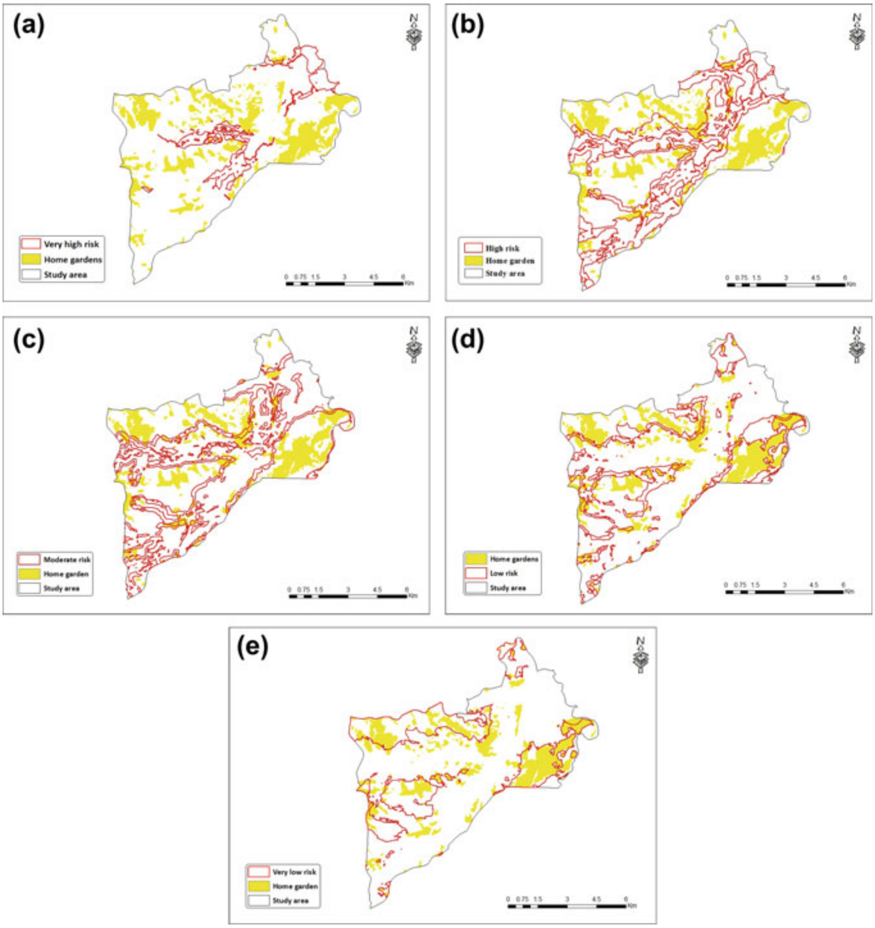

Fig. 4 Home gardens with **a** very high flood risk, **b** high flood risk, **c** moderate flood risk, **d** low flood risk and **e** very low flood risk

Table 7 Percentage of home gardens and paddy lands in different levels of flood risk in the study area of Porathivu Pattu DSD

Flood risk level	Total extend (sq.km)	Paddy lands (%)	Home gardens (%)
Very high	06	87	01
High	23	90	08
Moderate	13	62	15
Low	14	77	14
Very low	20	45	46

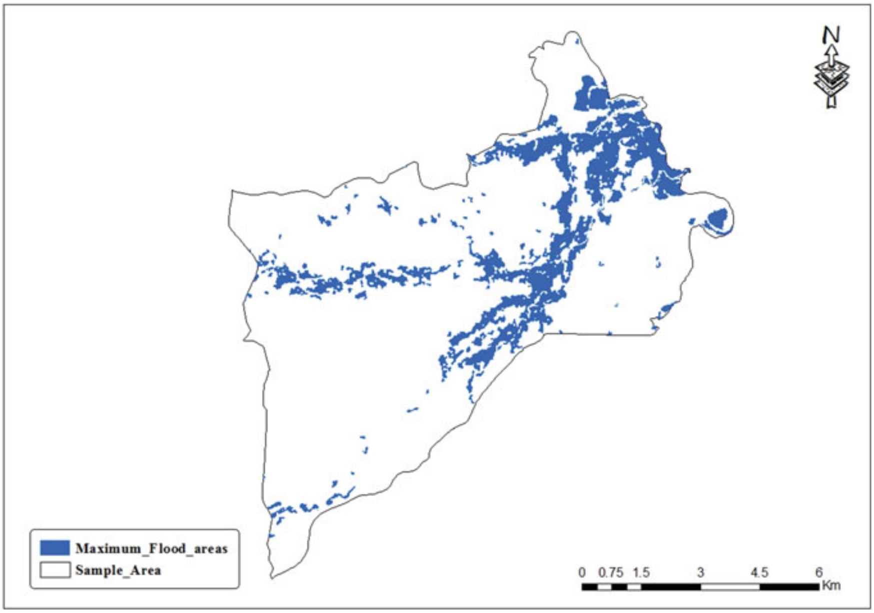

Fig. 5 Flood inundation map in the Porathivu Pattu DSD in December 2014

identified the maximum flood areas in 2014 (major flood), December in Eastern Province. It was shown in the Fig. 5.

Very High Flood Risk Areas: 2014 December Flood

As mentioned in the above flood risk areas of Porathivu Pattu DSD have been demarcated using Weighted Overlay Analysis. However, this map has to be validated and after the validation process the created map can be accepted. Therefore, the flood inundation map of the area created by DMC in December, 2014 was utilized for the validation process. When overlaying the DMC flood inundation map of 2014 and created flood risk map, it was found that 80% of the very high risk areas (Fig. 6a and 85% of the high risk areas Fig. 6b) in the created flood risk map were overlapped with flood inundation areas. Therefore, the created flood risk map of the Porathivu Pattu DSD can be highly acceptable.

5 Conclusion and Recommendation

This study identified the flood risk areas in the Porathivu Pattu DSD based on the flood hazard. These areas were situated in two river basins namely Andella basin and Navagiri basins. Four parameters, i.e. distance from the River, soil type, land use type and elevation were used to identify the risk areas. The ranks were assigned

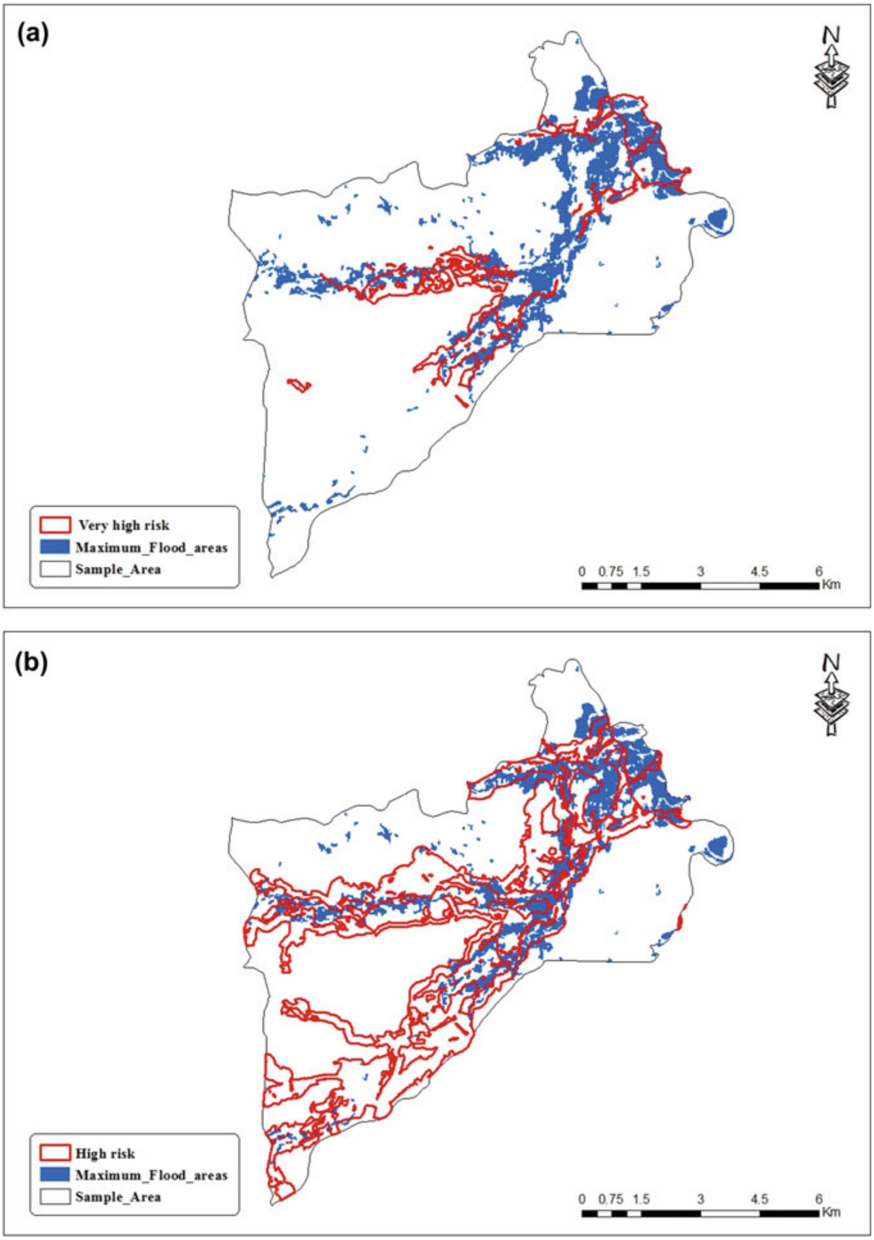

Fig. 6 **a** Very high flood risk areas, **b** High flood risk areas in 2014

to each parameter based on different influencing factors. The different weightages were assigned to each parameter. Considering of weightages and ranks, the Flood Hazard Map has been created using the weighted overlay analysis method. The flood risk has been classified into five categories, namely very low risk, low risk, moderate risk, high risk and very high risk. Further, the created flood risk map was validated by overlaying the 2014 December flood inundation map created by the DMC. The overlaying analysis found that about 82% flood risk areas are within the flood inundation areas in 2014. Therefore, it can be concluded that the flood risk map introduced in this study can be accepted. The flood risk classification revealed that very high, high, moderate, low and very low flood risk areas were 8%, 30%, 17%, 18% and 26% respectively. 87% of paddy lands are situated within the very high-risk area and high risk area (90% of paddy lands) will severely impact when flood situations will arise in future. The home gardens which were situated within the very high-risk area (01%), high risk area (08%) and moderate risk area (15%) will have the most severe impact when heavy rain will occur. It is revealed that the agricultural community of the Porathivu Pattu DSD has been facing many problems and challenges from the flood disaster every year. Based on the research findings of this study following recommendations can be suggested to minimize the impacts of flood disaster on the agriculture sector and the agricultural community in the Porathivu Pattu DSD in Batticaloa District.

Recommendation for Structural and Non-structural Measures

To minimize the flood impact, the study has proposed the several recommendations. It is recommended to build a proper water discharge drainage network around the cultivated lands and to clean the drainage system in proper time, e.g. Vettuchenai and Vellaveli area. More tanks can be built to preserve the rainwater and control the excess water going into the agricultural land especially for the paddy land. The smaller tanks should be reconstructed and maintained in proper time, e.g. Mandoor koottamunai kulam, Pan kulam, and Periya kulam etc. It is necessary to prohibit the destroying of the wetlands, which used for firewood and landfilling, e.g. Palugamam area. It is necessary to prevent, the constructing residences built near the Rivers, like Andella and Navagiri. Need to prevent the low landfilling, e.g. Vettuchenai, Kaakachiveddai, Aaanaikattiyaveli. Control the sand mining near the River banks of Mandur South, Koyilporathivu South, and Raanamadu water reservoirs. Based on the stakeholder's views, the study promoted to build flood resistant elevated houses where necessary. It is better to establish the erosion control methods such as plant mangroves, afforestation and etc. in river basins.

There are several non-structural measures to minimize the flood. This study proposed the agriculture community savings (e.g. Mobilize farmer groups into savings and credit funds). It is necessary to introduce the highest quality water-tolerant paddy and highland crop seeds stand in flood situations, e.g. Transplanted Aman (T. Aman). Introduce alternative crop practices like integrated farming e.g. Hydroponics method and multi crop practices in paddy land during non-cultivation season. Create alternative agriculture jobs e.g. curd production, milk production, and cow dung production as a natural fertilizer for highland crop cultivation is more applicable. An implementation of the flood risk transfer program (flood insurance) for the agriculture community, might be more benefited. It is necessary to conduct awareness programs for farmers to identify the best quality water-tolerant seeds to improve germination rates and yields. Unless implementing the suggested management activities, Porathivu Pattu DSD in Batticaloa District might lead to a backward position not only in its agriculture sector and community but also in the socio-economic sector.

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Policy Recommendations for Establishing a Long-Term Landslide Risk Management Strategy for Sri Lanka

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Abstract One of the observations during recent studies on major landslides in Sri Lanka, is non or lack of efforts for compliance with existing policies. Such shortcomings in policy compliance, which is also observed in many other countries, can be due to their poor technical understanding, implementation gaps, institutional weaknesses, interferences of influential parties etc. That indicates the necessity for efforts in better risk governance and importance of positioning the same around the theme of sustainable development. It also entails the introduction of appropriate institutional arrangement; the creation of appropriate policy & legal framework and the continuous resource allocations for mitigation of landslide risk. Within this context, setting up a development framework inclusive of landslide risk management interventions and climate change adaptation, will have very important long-term outcomes not only in reducing the future landslide risk but also in sustaining the gains of development. The Sri Lanka Community Landslide Risk Mitigation project, which was funded by the World Bank was an appropriate initiative and opportunity for identifying the essentials for improving the policy environment and compliance. The project study was based on Badulla District and covered assessment of degree of community vulnerability, analysis of major setbacks for policy compliance and identification of areas of improvement. The paper presents the outcome of the study and recommendations for creating an enabling policy environment and improving the risk management practices as a part of a long-term landslide disaster risk management strategy for the country.

Keywords Landslide disaster risk management strategy · Enabling environment

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1 Introduction

1.1 Problem

In the recent past, landslides have become one of the major disaster events in Sri Lanka, which has increased its frequency, magnitude as well as environmental, economic and social impacts. The higher precipitation events being the main triggering factor, sudden increase in landslide events in the country, presumably is influenced by the global climate change. In addition, it is also associated with the increased human interventions, land use changes and non or lack of efforts in compliance with existing policies. Hence it is worthwhile to study associated technical difficulties, implementation gaps, institutional weaknesses, etc. in order to identify necessary policy reforms and suggest proper monitoring mechanism to ensure policy compliance for effective landslide risk management.

1.2 Synthesis of the Literature Review of Cognate Studies in Several Other Risk Management Domains

The Sendai Framework for Disaster Risk Reduction (UNDRR 2020a) under its priority 2, highlights the importance of encouraging the establishment of necessary mechanisms and incentives to ensure high levels of compliance with existing safety enhancing provisions of sectoral laws and regulations, including those addressing land use & urban planning, building codes, etc. and to update them, where needed, to ensure an adequate focus on disaster risk management. Scoping studies of policy issues carried out under safe land project implemented in Europe, suggest that due to the likeliness of experiencing a higher frequency of landslides in future, it is necessary to identify and understand the deeper social, cultural and political conditions underlying current policy design, and the manner in which political change occurs and is potentially driven forward (Safe Land, 2011). At the meantime, See-Sew et al. (2009) making a suggestion on a template for policy and institutional framework, to serve as a blueprint to generate political commitment, stresses the need for setting-up of a lead organization or agency to ensure good governance to champion landslide mitigation and risk reduction in affected countries.

1.3 Opportunity

The World Bank Funded Community Landslide Risk Mitigation project was initiated to help the Government of Sri Lanka (GOSL) in unifying the landslide risk management efforts by all related government and other stakeholder agencies. The programme plans to establish a comprehensive framework and long-term operational action plan for landslide disaster risk management for the country. Hence it provides a window of opportunity for identifying the essentials for introducing policy reforms and presenting measures for monitoring policy compliance for creating an enabling environment as a part of said operational action plan and framework.

2 Research Methodology

The extensive review of literature carried out prior to the study provided an indication on expectations at Global level (UNDRR, 2020a), current policy environment related to landslide risk management in other risk domains (Safe Land, 2011), and similar strategies adapted in other countries (National Disaster Management Authority, Government of India, 2019). As guided by the same, it was decided to include in the subsequent desk review not only existing policies and practices but also the legal and institutional arrangements and to include several associated thematic areas namely: Conservation of forest and protection of upper watershed areas, land use planning and land management, protection of environment and natural resources, soil conservation, prevention of soil erosion and land degradation, water resources management and conservation and disaster risk management (World Bank, 2018). It was followed by a study of case studies on past landslides (Perera et al., 2018; Rathnasiri & Wijegunarathne, 2015). Key output of this task was selection of pilot areas for primary data collection, scrutinization of decision-making processes and identification of multiple set of stakeholders involved in the same. The pilot area selected for field data collection, considered to be one of the landslide hotspots and data collection methodology was determined collaboratively with mandated agency National Building Research Organization (NBRO). Primary data provided indications on the types of landslide vulnerability (UNDRR, 2020b), level of existing risk (UNDRR, 2020b) and reasons for gradual risk enhancement etc. Whereas the secondary data covered the aspects such as relevance of current polies and practices, challenges in administering them, current level of compliance, effectiveness of the institutional set up etc. which has been gathered through stakeholder consultations using district level workshops and focus group discussions held at various levels including community. At the end of the study, a national level workshop has been organized to validate the findings of the study, with the participation of around 100 attendees comprised of representatives from government, semi-government institutions, academia, INGO’s and NGOs, media.

3 Current Functions of NBRO, as the Mandated Agency for Landslide Risk Management

The mandated agency for landslide risk management in Sri Lanka, National Building Research Organization (NBRO) has implemented the Landslide Hazard Mapping Program (LHMP) since 1990. The LHMP was initially funded by the UNDP/UNHCR and since 1996 the program has been funded by the GOSL (NBRO, 2020). As an outcome of the program, it is expected to delineate the spatial distribution of landslide hazard within central highlands and produce hazard zonation maps in 1:50,000 and 1:10,000 scales, covering all landslide prone areas (NBRO, 2020). NBRO also carries out Special Investigations for most vulnerable areas.

Currently NBRO has several functional responsibilities as the mandated institution for landslide risk management such as the issuance of landslide early warning (Government of Sri Lanka, 2015), land suitability studies for development planning (NBRO, 2003), landslide risk assessment (NBRO, 2010), identification and prioritization of potentially vulnerable sites (NBRO, 2003) for mitigation and relocation of vulnerable families etc. The maps produced under LHMP are being utilized as the main instrument for above listed risk management interventions and physical planning at national and regional levels (NBRO, 2003).

4 The Pilot Area Selected for Field Studies and Observations on Contributory Factors for Increasing the Landslide Risk and Gaps in Management

Out of all landslide prone districts, Badulla District has shown the highest vulnerability, has more information coverage in terms of hazard maps, special investigation reports etc. Considering such factors, it was decided to carry out the study based on Badulla district. Since study period was limited to one year, 04 most vulnerable Divisional Secretariat Divisions (DSDs), namely Badulla DSD, Haputale DSD, Haliela DSD and Haldummulla DSD in Badulla district were chosen as the pilot study areas of the project. Subsequently a spatial database covering all elements at risk (UNDRR, 2020b) has been prepared for above pilot areas to facilitate assessment of exposure (Table 1) and vulnerabilities (UNDRR, 2020b) considering all elements at risk (UNDRR, 2020b).

The observations presented below were gathered during visits to pilot study area as well through district meetings (at Kegalle, Nuwara Eliya and Badulla), focus group meetings in pilot DSDs, community level meetings in landslide affected resettlement sites in other prone districts.

It is worthwhile to mention that many of the contributory factors observed and gaps identified in management and policy compliance are similar to the findings presented in the National Landslide Risk Management Strategy of India (National Disaster Management Authority, Government of India, 2019).

Table 1 No. of buildings in high hazard zones and special investigations carried out in pilot DSDs in Badulla district

DS Divison	Total area (km^2)	Total population	No. of GNDs	No. of special investigations carried out	Number of buildings in high hazard zone (as per the maps generated by NBRO)			
					Landslide are most likely to occur	Landslide are to be expected	Landslide have been occurred in past	Subsidence and rock fall
Haliela	165	90,517	55	415	251	4298	298	264
Badulla	51	75,042	26	174	79	2815	74	105
Haldummulla	412	37,558	27	410	103	2308	77	190
Haputale	72	49,798	25	403	98	1294	89	69
Total		252,915	133	1402	531	10,715	538	628

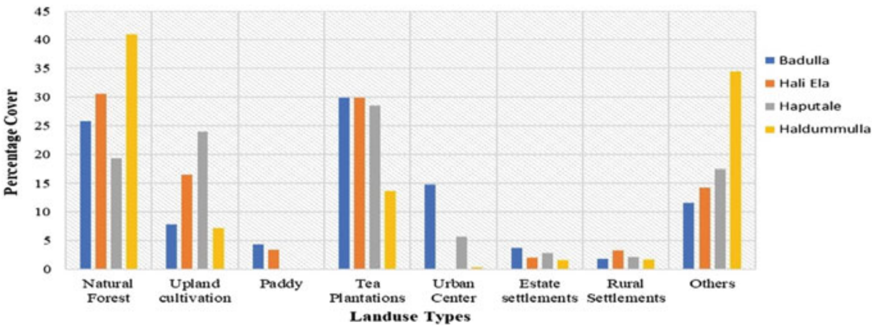

Fig. 1 Landuse types in 04 pilot DSDs

4.1 *Physical Vulnerability of Households and Characteristics*

The vulnerability assessment (UNDRR, 2020b) is expected to provide physical and socio-economic characteristics of households and shall contribute constructively in defining future strategies for long-term landslide risk management. In this regard, the most phenomenal factor observed is the high density of vulnerable households due to cluster housing found in semi-urban areas, including in tea estates, where line houses are predominant. Most of the houses were found to be constructed more than 50 years ago and majority are owner-built houses without any professional inputs during construction process. Type of terrain and the surrounding area of the houses seems to be mostly sloping ground and awareness of the occupants on construction practices on slopes, slope stabilization measures, appropriate techniques for slope excavation, filling etc. was found to be limited. This knowledge factor is very important to maintain a safer living environment. NBRO is provided with a new role by the National Council for Disaster Management (NCDM) (Sri Lanka Disaster Management Act No. 13, 2005) to oversee the development interventions in landslide prone areas including housing (NBRO, 2003; Government of Sri Lanka, 2015). However, due to absence of regulatory powers, NBRO's ability to influence resilient construction or improve the quality of housing stock is found to be minimal (NBRO, 2003; Government of Sri Lanka, 2015) (Fig. 1).

4.2 *Socio-Economic Factors and Livelihood Related Vulnerabilities*

The major land use type observed within the 04 pilot areas is tea plantations and a considerable percentage of balance area is covered with natural forestry and agro-forestry. The main livelihoods of the households were found to be more rural or semi-urban and predominantly connected with agriculture sector such as homesteads, vegetable smallholdings and rainfed rice paddy cultivations. Mostly they are self-employed and/or heavily dependent on the daily wages except the plantation sector workers and small business community. There is a small percentage, who depends on skill-based employment such as craftsperson, artisans, house builders, small scale building material manufactures etc.

If they have an option for relocation (UNDRR, 2020b), most vulnerable households have shown keen interest in relocating within the same area due to the fact that they have an opportunity to continue with the existing livelihoods as well as the possibility of maintaining social and cultural relationships within a familiar environment.

4.3 Unauthorized Settlements on Higher Slopes

Influx of rural population into urban areas are getting higher in the pilot study areas, although not at the same rate as seen in some of the major cities. It is mainly due to better employment opportunities, economic benefits, better education, and other facilities as well as services offered in urban areas and avoidance of difficulties in commuting. Among them certain percentage from lower and upper middle class tend to move into urban areas on permanent basis and many find it difficult to locate in suitable safer areas for living. Many such settlement clusters are located in around cities (refer example from Haputale Urban Council area in Fig. 2) and urban centers and most of them are found to be unauthorized settlements.

Fig. 2 Unauthorized houses constructed on a steep slope within Haputhale urban council area

The other unfortunate factor is the complacency of local governments in imposing related regulations to discourage them due to various reasons.

4.4 Challenges in Resettlement of Vulnerable Families

Relocation deals with a set of most delicate and sensitive issues including land ownership. Hence, it needs careful planning as it is expected to build not only new settlements but also new routine or lifestyle for those involved. After tsunami, major systematic attempt for resettlement of disaster affected people were taken after "Meeriyabedda" (Rathnasiri & Wijegunarathne, 2015) and "Samasara Kanda" (Perera et al., 2018) landslide events in Badulla and Kegalle Districts. The procedure was defined by a Cabinet decision dated 13th November 2014, but subsequent reviews of the process adapted, revealed the complexity and intricacies of the related procedure. Such complexities created confusion, overlapping and severe coordination issues prompting the creation of a much more simple, well-coordinated, and effective disaster induced resettlement mechanism.

4.5 Cultivation Practices that Contribute to Increasing Risk

Tea and rubber plantations found to be the two major land users found in landslide prone areas. In recent years many cases of landslides have been reported in them due to some recent changes taken place in terms of plant cultivars/species, cultivation methods, maintenance etc. purely considering the reduction of the associated cost factor. The post-disaster investigations carried out by NBRO in Meeriyabedda (Rathnasiri & Wijegunarathne, 2015), which was responsible for loss of 37 lives and destructions to 75 buildings, have revealed that the excessive ingress of water into already destabilized mass had created the landslide. Similar conditions have been observed in several other landslides found within the study area. Moreover, due to scarcity of land, unauthorized clearance of forest areas and cultivation on steep hill slopes are happening in alarming pace within the study area and elsewhere in landslide prone districts.

4.6 Settlements in High Hazard Areas Such as Areas with Rockfalls, Dormant Landslides, Previous Debris-Flow Areas *Etc*.

During field studies several existing settlements in areas with rockfalls, dormant landslide masses (Fig. 3), previous debris-flow areas etc. have been witnessed. Such

Fig. 3 A set of line houses located on dormant landslide mass

cluster settlements are observed in tea plantations mainly due to the reason that they allocate only unproductive land for accommodating line houses for workers as a practice.

4.7 Lack of Preparedness Planning and Poor Response for Early Warning (EW)

NBRO and Disaster Management Center (DMC) have made reasonable attempt to ensure active community participation in responding to landslide early warning (Government of Sri Lanka, 2015; Sri Lanka Disaster Management Act No. 13, 2005), but the response at community level desired to have further improvements. It is essential to have efforts in preparedness planning and routine conduct of rehearsals as well to have a community feedback mechanism to monitor the success.

4.8 Environment Problems Associated with Infrastructure Improvement Projects (Road Projects, Water Supply Projects *Etc*.)

Currently, a significant amount of environment problems is observed in the study area that are associated with infrastructure improvement projects. Mainly such problems are a result of slopes left unattended or without proper maintenance after commercial level earth excavation, quarry operations, sand mining etc. At the meantime, when excavation of slopes is not carried out following appropriate engineering guidelines, such slopes can fail during monsoon periods. As observed during field visits to pilot study area, loose soils generated due to such failures are transported and dumped into vacant lands in the down slope, as a common practice. These soils get eroded and naturally transported subsequently to drainage systems, creating flood risks in lower areas. It will also result in degradation of productive agricultural lands. Often slope failures will create inconvenience to commuters due to transportation disruptions during rainy seasons.

5 Essentials for Creating an Enabling Environment and Developing a Long-Term Strategy for the Country

From the above, it is evident that there are current practices and implementation gaps that do not support efficient management of landslide prone areas. If such practices are continued, the landslide risk will grow exponentially in future and managing the same will not be technically feasible or economically cost effective. There is an essential need for introduction of strategies that will reduce the existing risk, do not allow creating new risk in future. The approach taken by India is a good example, in which they have recommended formulation of land use policies and techno-legal regime, update and enforcement of building regulations, review and revision of codes and guidelines, propose amendments to number of existing legislations etc. (National Disaster Management Authority, Government of India, 2019). Forthcoming efforts are inevitable by the Sri Lankan authorities in terms of policy reforms and measures for improvement of the monitoring mechanism to ensure better policy practice and compliance. Additionally, such strategies should be capable of meeting the consequences arising due to events that are unpredictable in nature. Invariably, such strategies should be forward looking, technically sound but flexible enough to allow modifications when and where necessary.

The process adapted for such policy reforms shall ensure ownership of all key government and non-government stakeholders and influential enough in guiding short, medium as well as long term planning and investment decisions across for transition in to a resilient society. During the validation workshop, efforts have been made to identify essential strategies for creating an enabling environment and number of recommendations that were made in this direction, are presented below.

5.1 Reviewing Existing Policy Environment and Legal Processes to Integrate Landslide Risk Management

An assessment study conducted on the laws, regulations, and policies (World Bank, 2018) in order to understand their degree of applicability for landslide risk management, revealed that a number of policies of relevance are in existence as various enactments, ordinances, regulatory frameworks such as Land Use Policy Planning, Forest Conservation, Soil Conservation, State Land Ordinance, Town and Country Planning Ordinance, Environment Impact Assessment, Mining & Mineral Exploration etc. Those have been introduced from time to time by GOSL, since the colonial era to the present. Most of them are connected with overlapping responsibilities, and number of government institutions are established to oversee them. One of the notable findings of the study (World Bank, 2018) is that, before enforcement of Sri Lanka Disaster Management Act No. 13, the policy regulations had little mention about disaster risk management and hence, there is an essential need to integrate the subject of landslide risk management in an appropriate way into the scope and the subject areas described in various enactments, policies, regulations, ordinances of relevance or to undertake suitable policy reforms.

5.2 Developing Operational Guidelines to Arrest the Challenge of Growing Risk Due to Unregulated Human Interventions

It is essential to introduce operational guidelines, spelling out the responsibilities and the accountability for executing respective mandates and functions by various authorities responsible for disciplines such as human settlement & land use planning, housing, building construction, roads & infrastructure development, removal of earth/rock in commercial scale, agricultural practices in hill slopes, rehabilitation of abandoned land, etc. Subsequently the NCDM (Sri Lanka Disaster Management Act No. 13, 2005), can grant permission for adoption of them to be the national operational guidelines and standard practices for administering related mandates by respective agencies.

5.3 Enhancing the Legal Mandate and Technical Capacity of NBRO

The current legal status of the National Building Research Organization (NBRO, 1986, 2003, 2010; Government of Sri Lanka, 2015) is a significant weak point and a hindering factor for NBRO to function effectively as the focal point for landslide risk management (NBRO, 2010; Government of Sri Lanka, 2015). As mentioned in Sect. 2 above, NBRO, has number of related responsibilities (Government of Sri Lanka, 2015) but has limited legal authority for executing control of any inappropriate and unfitting activities, which contribute to increase in landslide risk. The current legal status is desired to be improved to make NBRO a fully operational legal entity that will cater to the multiple requirements of the country covering related research, technical services and monitoring functions.

5.4 Explore the Possibilities for Undertaking Alternative Options for Mitigating the Risk in Landslide Prone Areas

In the past, country has largely relied on conventional engineering solutions for landslide risk mitigation. It is necessary to explore the possibility of other possible options such as Nature-based Solutions (NbS) and/or hybrid solutions (undertaken in combination with other engineering measures) (World Bank, 2018). A review on community based soil-bioengineering techniques implemented in Honduras (Hostettler et al., 2019), suggests that for community level, NbS offer a set of viable, cost effective and environmentally friendly practices for addressing certain problems that cannot be addressed utilizing the conventional techniques due to higher cost and other factors.

5.5 Setting Up People Centered Early Warning (EW) Mechanism to Improve the Preparedness for Responding to EW

Currently, there are many challenges in addressing the issue of last mile dissemination of landslide early warning. The awareness of the people exposed to landslide hazard is important for their response to a warning, and communication and sociological problems must be considered and addressed when designing an effective landslide advisory scheme (Guzzeti et al., 2020). Creating unified standard operation system for facilitation of EW dissemination is essential, forming effective networks between technical institutions, district authorities and high-risk communities.

5.6 Enhance the Effectiveness of Disaster Induced Resettlement Programs Through Ensuring the Participation of Beneficiaries

The gaps that have been observed in the system adapted for landslide induced resettlement, seems to be related to policy issues, implementation process, legal and institutional set up etc. Currently resettlement/relocation processes are often dominated by the government agencies, overriding the perspectives of the affected persons. Hence, the process should be reviewed to ensure active participation of beneficiaries in decision making to enhance quality and resultant outcome of disaster induced resettlement programs and also to ensure their ownership. It is essential to have special program for rehabilitation and productive use of land abandoned due to relocation of families living in high hazard areas, under-utilized and poorly managed land within the plantation sector.

6 Conclusions

For efficient management of landslide-prone areas in the country, a long-term risk management framework is essential. The said framework entails a strategy that helps in creating an enabling environment built around appropriate policy, legal and institutional arrangements necessary, for effective management of landslide prone areas. Inadequacies discussed above in this regard should be addressed through suggested policy reforms. Poor technical understanding, implementation gaps, institutional weaknesses, etc. observed to be the main reasons for lack of compliance with current policies and procedures. Hence, it is essential to introduce an effective system for administering them and mechanism for regular monitoring in future.

To ensure effective functioning of NBRO, as the focal agency for landslide disaster risk management, the current legal status of the institution is desired to be upgraded so that NBRO will be able to function as a monitoring agency, while enhancing its current technical capacity for undertaking landslide studies, services, research and other landslide risk management functions. Building capacity of other stakeholder institutions, including community members also is an essential need.

The policy reforms recommended above, should be considered as a progressive approach that will reduce the existing risk, do not allow creating future risk and capable of meeting the consequences arising due to events that are unpredictable. The approach for building community resilience, and corresponding decisions on risk management, as well the related investment should be governed by potential technical and socio-economic outcomes. The approach should be forward looking, technically sound but flexible enough to allow modifications when and where necessary. It should be influential enough in guiding short, medium as well as long term development planning and investment decisions across for transition into a resilient society in the near future.

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Evaluation of the Impacts of the Salinity Barrage in Kelani Ganga Using 1D-2D Hydraulic Model in Terms of Flooding

K. K. G. I. L. Siriwardena, S. Widanapathirana, and P. A. A. P. K. Pannala

Abstract Kelani Ganga is the main source to cater the water requirement of Colombo and Gampaha Districts, Sri Lanka. The main water treatment plant located at Ambatale, with the expanding water requirement of the Port City in Colombo, the demand gap of Ambatale Water Treatment Plant (WTP) will be increased up to about 15.2 m^3/s (1.31 MCM/day) by 2040. Kalani river bed has been considerably lowered since 1990s, as excessive sand mining. The intake at Ambathale was frequently subjected to salinity intrusion during the dry periods. As a result, National Water Supply and Drainage Board (NWS&DB) constructed a barrage across the river just downstream of the Ambathale intake to overcome this problem. With the introduction of the barrage, the upstream water levels of the barrage has been increased during the recent floods. A cross sectional survey data was used to gather information on prevailing conditions in river morphology. This paper is evaluated the flood impacts of the barrier for 2016 and 2017 flood events using the hydro-dynamic 1D-2D Model study, built using Flood Modeller and TUFLOW linked software. Though the barrier is most feasible solution for salinity intrusion, it was created the head loss of 0.5 m, and the backwater effect about 10 km upstream for 2016 event and it is recommended either to keep the barrage top level at about −2.5 m AMSL to avoid the significant backwater effect or to move the water intake to the upstream to minimize the impact to the public during the flooding.

Keywords Salinity barrier · Hydro-dynamic 1D-2D model · Ambathale · Evaluation · NWS&DB

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1 Introduction

1.1 Overview

Floods are the most destructive and common Nature-based disaster, which has the effect on a large scale all over the world (Dilley, 2005). More than 170,000 people died due to recurrent floods world widely from 1980 to 2000 and more than 90 countries in the world are vulnerable to disastrous flood (UNDP, 2004). In June 1989, the western part of Sri Lanka experienced a natural disaster bordering three major river basins, namely Kelani Ganga, Kalu Ganga, and Gin Ganga. High-intensity rainfall caused the lower catchment suffered from flash floods. It was reported that 300 lives were lost, 15,000 houses were damaged, and 225,000 people became homeless during this disaster and the total damage was estimated at Rs.120 million (Niroshani, 2012).

Though 2016 flood levels were lower than 1989 flood levels, the damage of the 2016 flood was significantly higher due to the longer durations of inundations, and the irregular developments that took place in the floodplain (Hettiarachchi, 2017). United Nations reported that these were the worst floods reported in 25 years, 5,037 houses have been estimated as destroyed, while 104 people are known to have died and Sri Lanka experienced the highest economic loss in South Asia with total damages exceeding Rs 82,650 million due to the floods in May 2016 (Silva, 2016).

1.2 Project Area

Kelani Ganga basin is the seventh largest river basin in Sri Lanka with a catchment area of 2292 km^2. River begins on the slopes of the western rim of the Central Highlands at about 1500 m AMSL and annual average rainfall is varied from 1800 to 5700 mm in the basin (Fig. 1). River annually carries about 4225 MCM of water to the sea at the sea outfall after passing about 145 km.

There is an abrupt change in the slope of the Kelani River around Hanwella, which is 35 km upstream of the sea, as shown in Digital Elevation Model (DEM) (Fig. 2). River has only a mild slope upto Hanwella and this change in the slope of the river plays a large role from flooding perspective (Ltd, W.A.I., 2018).

River gauging stations along Kelani ganga maintained by Irrigation Department (ID) are shown in Fig. 3. River flow varies from 2.5 m^3/s in the dry season to 1500 m^3/s during floods, or as much as 2500 m^3/s during larger flood events (Ltd, W.A.I., 2018).

1.3 Salinity Intrusion and Importance of the Water Supply

Being the main source of water supply for domestic and industrial needs of Colombo and its suburbs, around 80% of the greater Colombo area is supplied from Ambathale

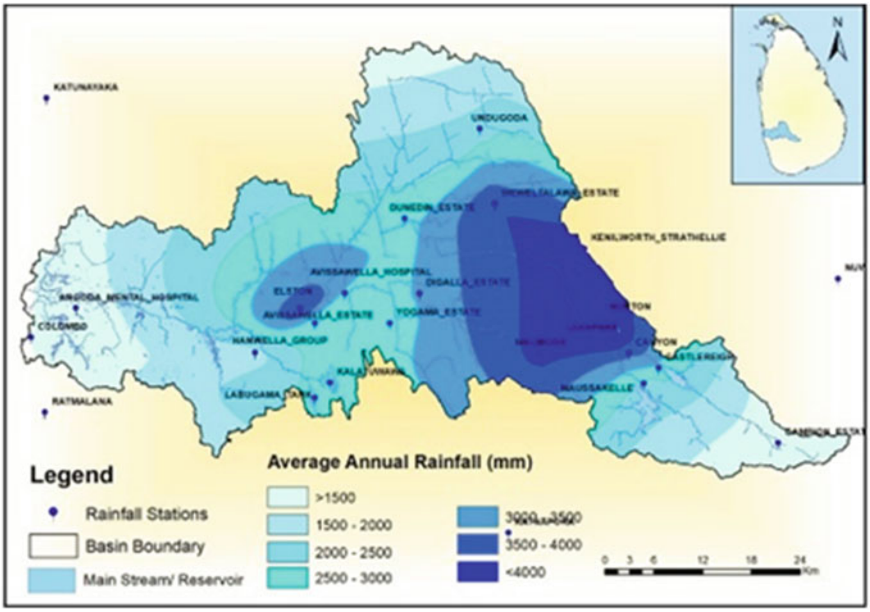


Fig. 1 Rainfall variation in Kelani Ganga basin

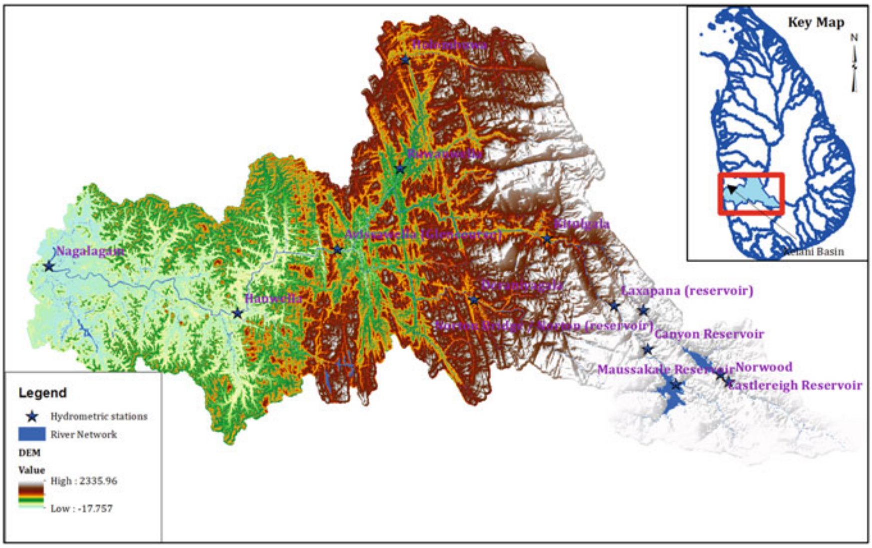


Fig. 2 Elevation variation in Kelani Ganga basin

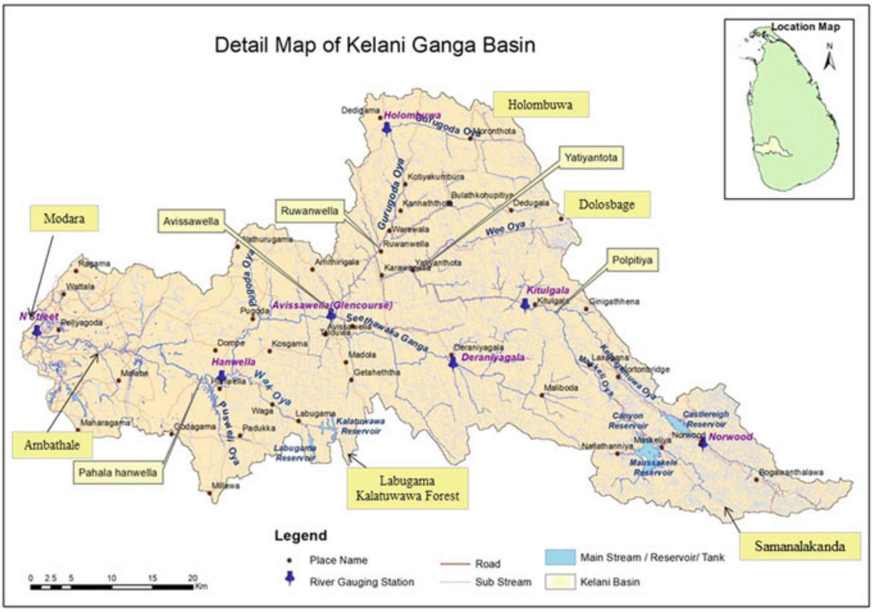


Fig. 3 River gauging stations, reservoirs and streams in the basin

Water Treatment Plant (WTP). Salinity intrusion has become an ever-increasing problem in the lower reach of the Kelani Ganga and it has exposed the Ambathale water intakes several times in the past.

The evaluation of the impacts of the Salinity Barrage in Kelani Ganga using 1-Dimensional and 2-Dimensional (1D-2D) hydraulic model in terms of flooding was carried out to fill the gaps of the research on the salinity barrier and its drawbacks to the society during the study. Calibrated and validated 1D-2D linked Hydraulic model was built using Flood Modeller Pro and Two-dimensional Unsteady FLOW (TUFLOW) software packages to evaluate the impacts of the Salinity Barrage in Kelani Ganga in terms of floods in 2016 and 2017. The optimum top level of the barrier was evaluated during the study to minimize the impact of the flooding to the general public.

2 Literature Summary

2.1 Floods in Kelani Ganga and Its Impact

Recently, floods are become more frequent and Kelani ganga has a long history of flooding. A river gauge has been placed in Nagalagam Street since 1837 and it has continuous operation up to now. According to the flood classification (Table 1), 3 critical floods have occurred since 1870s, while, there has been a flood of ‘minor or higher’ classification 27 times within 180 years for all flood events. During last 50 years, there were 3 dangerous, 3 major floods and 2 minor floods occurred, as shown in Table 2. Therefore, 2016 flood is considered as ‘Major flood’, while 2017 flood is considered as ‘Minor flood’.

2.2 Model Description

Flood Modeller Pro is a computer program that simulates the flow of water through river channels and across floodplains using a range of one- and two-dimensional hydraulic solvers, developed by Jacobs and is the successor to ISIS, which was in development for almost 40 years (GISuser, 2014).

TUFLOW is an established 1-Dimensional (1D) and 2 Dimensional (2D) modelling software for simulating flood and tidal flow. Powerful solvers have been successfully applied to a wide range of applications for over 25 years. It is particularly suited for modelling flooding of rivers and creeks with complex flow patterns, overland and piped flows through urban areas, estuarine and coastal tide hydraulics as well as inundation from storm tides and tsunamis and the proven 2D solver uses

Table 1 Flood classification at Nagalagam street

No.	Flood classification	Water level at Nagalagam street (m AMSL)
1	Minor flood	≥1.52
2	Major flood	≥2.13
3	Dangerous flood	≥2.74
4	Critical flood	≥3.66

(*Source* Hydrology division, ID)

Table 2 Historic floods at Nagalagam street and their classification for last 5 decades

Year/Month	Water level (m AMSL) at Nagalagam street	Flood classification
1966 Sept.	2.64	Major
1966 Oct.	2.74	Dangerous
1967 Oct.	2.80	Dangerous
1971 Sept.	2.23	Major
1989 Jun.	2.80	Dangerous
2011 May	1.65	Minor
2016 May	2.33	Major
2017 May	1.83	Minor

(*Source*: Hydrology division, ID)

an Alternating Direction Implicit (ADI) scheme to solve the full 2D free surface shallow water flow equations (Anon, 2015).

2.3 Barrier Details for Sensitivity Analysis

Ambathale Salinity Barrier is a permanent structure located about 15 m downstream to existing Ambathale intake. The main features of the structure are given in below (Figs. 4 and 5).

1. The main barrier of 75 m length with sill level at −0.5 m AMSL
2. Barrier top level of 75 m, can be increased its level upto +1.0 m AMSL using sang bags
3. Raft package of 15 m length with sill level at −2.0 m AMSL
4. Sedimentation excluding channel with sill level at −2.0 m AMSL

Fig. 4 Location map of salinity barrier (*Source* Google earth)

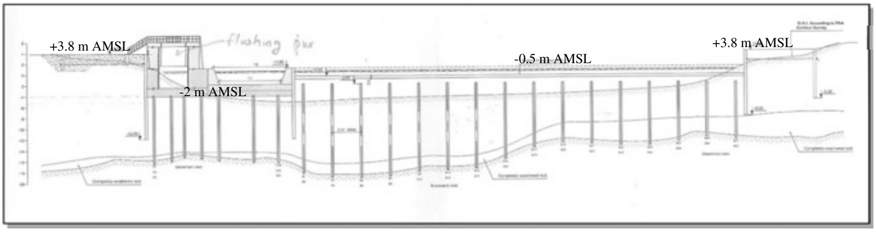
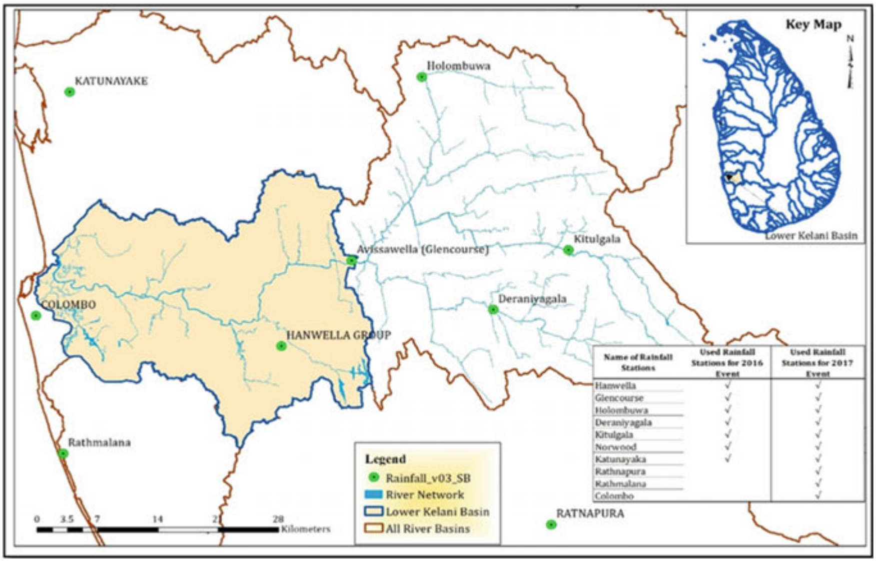


Fig. 5 Cross section of main barrage (*Source* NWS&DB)

3 Data and the Method

River cross sections were used from Glencourse to sea outfall to represent the river channel as 1D component, while as 4 m DEM is used to represent the rest of the basin area in 2D (Fig. 6).

Re-rated flow for Glencourse Gauging station and observed tidal data was given as upstream boundary condition, and downstream boundary condition to the model respectively. Rainfall data is used as hourly time-step by considering the whole catchment from Glencourse gauging station (Fig. 6) and it is given as another boundary condition for the whole duration of the flood for 2016 and 2017 flood events. Roughness is used based on the landuse of the basin and infiltration loss is calculated in 2D floodplain to TUFLOW model using Green Ampt equation based on the soil parameters. Surveyed Cross sections are used from Bathematic Survey, which was



Name of Rainfall Stations	Used Rainfall Stations for 2016 Event	Used Rainfall Stations for 2017 Event
Hanwella	√	√
Glencourse	√	√
Holombuwa	√	√
Deraniyagala	√	√
Kitulgala	√	√
Norwood	√	√
Katunayaka	√	√
Rathnapura		√
Rathmalana		√
Colombo		√

Fig. 6 Modelled area with the rainfall stations used for analysis

done by Navy and surveyed cross sections from Climate Resilience Improvement Project (CRIP) from Glencourse to Sea outfall and the space of two cross section is varied from about 30 m to 1 km based on the location.

Then the whole 1D-2D hydraulic model was developed incorporating its structures and salinity barrier (Figs. 4 and 5) and the model was calibrated and validated with the recorded water levels at Ambathale and Hanwella river gauging stations (Fig. 3). The impact assessment of the salinity barrier was analysed for the respective events using the calibrated and validated model to avoid the significant head loss to the upstream to minimize the impact to the public during the flooding. The head loss across the Salinity Barrier is estimated by head loss factors in Flood Modeller hydraulic model and 1D-2D model was calibrated for 2016 and verified for 2017 flood event.

Steady flows were used to ensure the initial conditions of the Flood Modeller hydrodynamic model to denote unsteady flow for calibration of the model as well as the impact assessment of the barrier.

4 Results and Discussion

4.1 General

As a result of sand mining, the bed and banks were eroded making the river wider and deeper (Wijesinghe, 2010). It is evident that changes in river morphology taken place in last 25 years that could alter the flood levels and conveyance capacity of the river rapidly. As a result of it, salinity intrusion became a real issue to supply drinking water to public. The seriousness of the problem of salinity at Ambathale had been recognized over two decades ago and the problem has been aggravated due to lowering of the river bed due to excessive sand mining. As the demand for sand has been increased in Greater Colombo area, sand mining was continued lowering the river bed, leading more salinity intrusion during the dry season (Danish Hydraulic Institute in association with Lanka Hydraulic Institute, 1993). In the Kelani ganga, it was found that the saline wedge extends upstream around 15 km and it moves up and down around 4 km by flood and ebb tides (Danish Hydraulic Institute in association with Lanka Hydraulic Institute, 1993). The lengthening of the saline wedge during the low flow period has suspended water abstraction partially or fully at the Ambathale intake several times in the past (Danish Hydraulic Institute in association with Lanka Hydraulic Institute, 1993).

Although providing a barrage across the river at Ambathale was the only immediate solution to prevent salinity, its impacts on flooding had been assessed carefully as it may increase the flood levels in upstream during the study. Hence, the model was calibrated at Hanwella and Ambathale gauging stations and calibration and validation plots of the model for Hanwella and Ambathale stations are shown in Figs. 7 and 8 for 2016 and 2017 events. Figure 7 shows the modelled levels for 2016 event is a good match to the observed water levels in terms of timing, rate of rise and

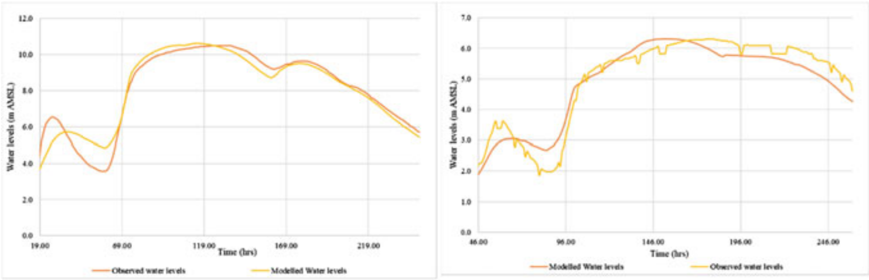


Fig. 7 Calibration plots for Hanwella and Ambathale for 2016 flood event

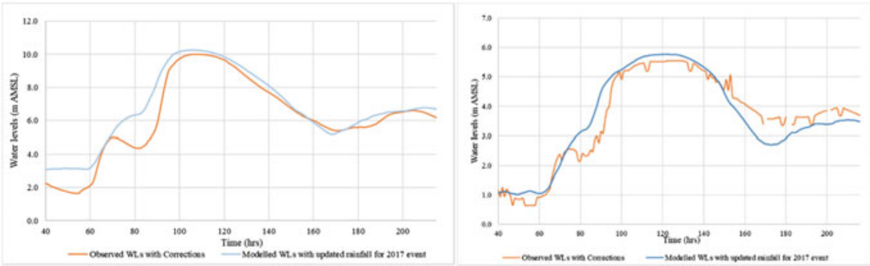


Fig. 8 Validation plots for Hanwella and Ambathale for 2017 flood event

recession and peak at Hanwella and Ambathale stations. Hanwella and Ambathale are considered for comparison of flood events, as the gauging stations are mainly located in those stations.

Modelled Peak water levels are marginally higher than 1% and 0.1% of the observed water levels for calibration at Hanwella and Ambathale gauging stations, respectively and they are 2.6% and 3.9% higher than the observed water levels for the same stations, respectively for validation. As they are within the model's tolerance limits, the model is used for the further impact analysis of the barrier of the study. In addition to that, flood map calibration and validation was done in 2D for the lower Kelani basin for 2016 and 2017 events, respectively and shown in Fig. 9. Calibrated and validated 2D flood inundation maps show that the well matched in 2D inundation extents as well as flood depths for both events. Some local drainage flooding are shown along Kalu Ela tributary in and around Wattala area for both 2016 and 2017 flood events (Fig. 9).

Observed levels at the Ambathale Barrier for 2016 and 2017 flood event are given in Table 3 with its top levels, as the its top levels were not same during the two flood events. Model was run for 2016 and 2017 events, respectively and possible impacts on flood levels of the river was analyzed with and without the barrier and comparison of water levels and flows are given in Table 4 and Table 5 respectively. As the Tables 4 and 5, it is clearly shown that the backwater impact is affected upto Kaduwela area.

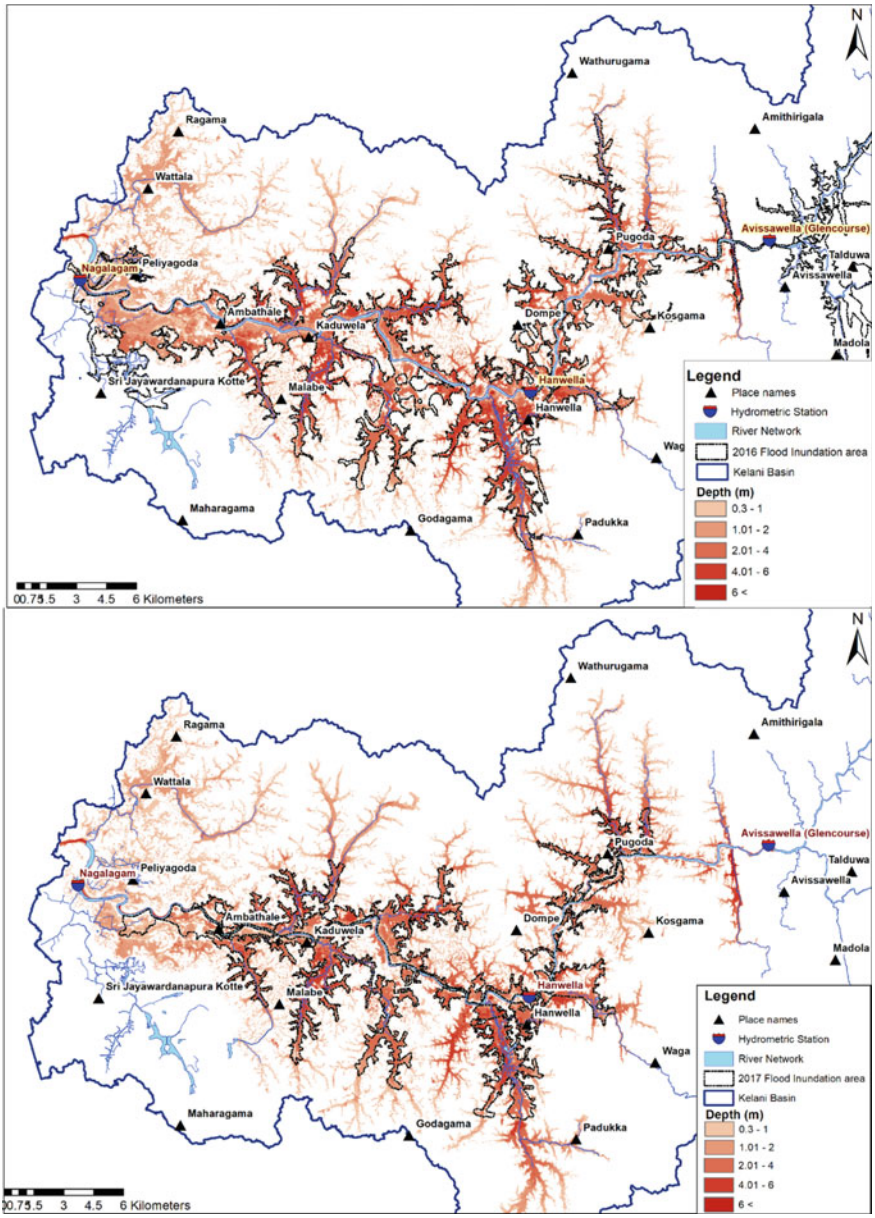


Fig. 9 Flood extent calibration and validation in 2D for the lower Kelani basin for 2016 (top) and 2017 (bottom) events

Table 3 Observed levels at the Ambathale barrier for 2016 and 2017 flood event

Description	Observed water levels (m AMSL)
Maximum water level for 2016 event with sand bags to the top level at 0.4 m AMSL	6.22
Maximum water level for 2017 event with sand bags to the top level at −0.2 m AMSL	5.55

Table 4 Comparison of maximum water levels (m MSL) for 2016 and 2017 floods

Location	2016 Flood (m AMSL)		2017 Flood (m AMSL)	
	With barrier	Without barrier	With barrier	Without barrier
Hanwella	10.62	10.62	10.25	10.25
Kaduwela	8.35	8.3	7.97	7.93
Just upstream of salinity barrier	6.22	5.73	5.82	5.35
Nagalagam street	2.33	2.33	1.89	1.89

Table 5 Comparison of maximum flows (m MSL) for 2016 and 2017 floods

Location	2016 Flood (m^3/s)		2017 Flood (m^3/s)	
	With barrier	Without barrier	With barrier	Without barrier
Hanwella	2083	2087	1916	1914
Kaduwela	1812	1829	1721	1728
Just upstream of salinity barrier	1645	1900	1545	1670
Nagalagam street	1936	1936	1636	1636

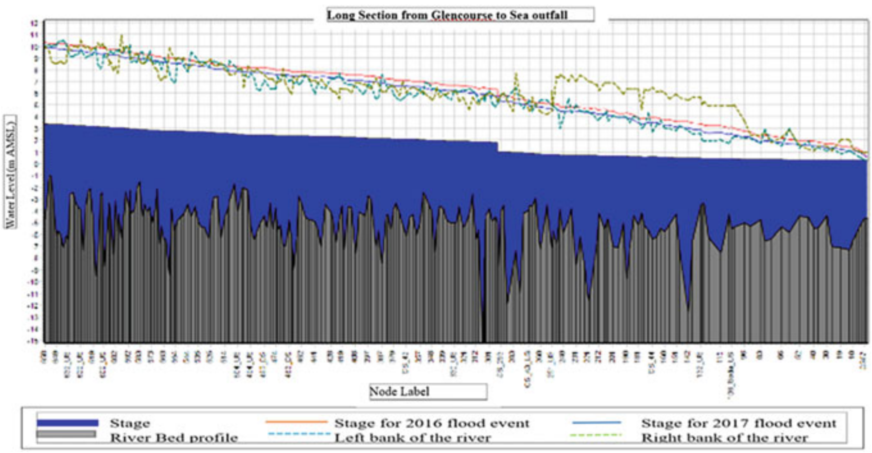


Fig. 10 Longitudinal profile for 2016 and 2017 flood events along Kelani river (Modelled results of 1D-2D model built in flood modeller)

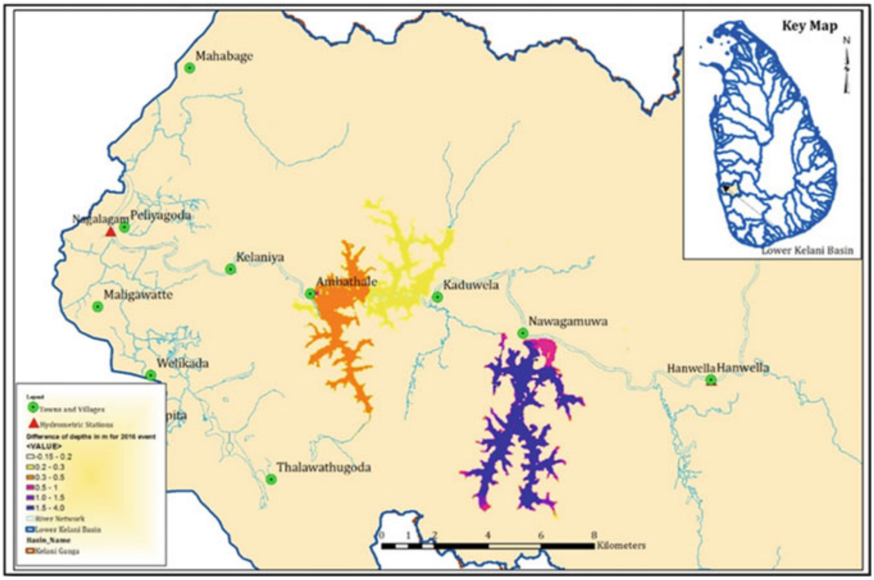


Fig. 11 Flood depth differences due to Salinity Barrier at Ambathale for 2016 flood event

Longitudinal profile of the 1D Hydraulic model are given in Fig. 10 and the backwater effect can be clearly showed in the figure, due to the Salinity Barrier during 2016 and 2017 flood events. Mainly two flood events were considered for this analysis and 2016 and 2017 events were considered as flood of 20 year return period and about 4 year return period respectively with respective to Glecourse gauging station in GEV distribution (Ltd, W.A.I., 2018). As 2016 event has overbank flow, the significant flood depth differences can be seen in 2D due to the Barrier (Fig. 11) and it didn't show the significant water depth variations for 2017 event, as 2017 event has not overbanked. The backwater effect is affected about 10 km upstream from the barrier for 2016 event and it is about 4 km for 2017 event as the model results, hence it impacts on increasing the flooding in upstream.

As the Table 4, the backwater effect can be seen significantly upto Kaduwela area, while it is not shown the significant backwater effect at Hanwella gauging station.

4.2 Sensitivity Analysis by Increasing and Decreasing the Barrier Different Levels

Sensitivity analysis was done to compare the water level rise upstream for the same flow by changing the barrier levels from + 0.4 m AMSL to -3.5 m AMSL to minimize the backwater effect for the respective event.

Tables 6 and 7 show the water level rise immediately upstream to the barrier for different levels of the barrier for 2016 and 2017 events and the backwater impact is varied from 0.1 m to 0.5 m for the selected two flood events.

Table 6 Water level rise immediately upstream of the barrier for different levels of the barrier for 2016 flood event

Description	During 2016 event (0.4 m AMSL)	Reduced the spill level upto 0.0 m AMSL	Reduced the spill level upto −0.5 m AMSL	Reduced the spill level upto −1.5 m AMSL	Reduced the spill level upto −2.5 m AMSL	Reduced the spill level upto −3.5 m AMSL
Maximum water level with barrier	6.22	5.85	5.8	5.72	5.65	5.6
Maximum water level without barrier	5.73	5.37	5.37	5.37	5.37	5.37
Level difference due to the barrier	0.49	0.48	0.43	0.35	0.28	0.23

Table 7 Water level rise immediately upstream of the barrier for different levels of the barrier for 2017 flood event

Description	During 2017 event (−0.2 m AMSL)	Reduced the spill level upto −0.5 m AMSL	Reduced the spill level upto −1.5 m AMSL	Reduced the spill level upto −2.5 m AMSL	Reduced the spill level upto −3.5 m AMSL
Maximum water level with barrier	5.82	5.79	5.67	5.63	5.45
Maximum water level without barrier	5.36	5.35	5.35	5.35	5.35
Level difference due to the barrier	0.46	0.44	0.32	0.28	0.10

5 Conclusion and Recommendations

Calibration and validation of the 1D-2D model shows the well matched in 2D as well as the water levels at gauging stations shows that they are within the model's tolerance limits, the model is endorsed for the further impact assessment of the barrier. This study concluded that there's an impact to flood due to the Barrier during recent floods.

Though the permanent barrier is the most feasible solution for the salinity intrusion, the alternative methods are to be studied to minimize the backwater effect of the upstream of Barrier. It is anlaysed that the backwater effect is affected about 10 km upstream from the barrier for 2016 event and it is about 4 km for 2017 event and it was modelled 0.49 m and 0.46 m head loss for 2016 and 2017 flood events, respectively, as the model results. It is also concluded that the backwater effect is optimum at about −2.5 m AMSL, as it has not shown significant backwater effect at that level. Hence it is recommended to find the suitable alternative structural measures (gates or balloons) on the proposed optimum top level to minimize the impact to the public, as it acts as a barrier to the flow during the flooding. It is also recommended to the government of Sri Lanka to take policy decisions for controlling sand extraction to prevent recurring the same effect along the river and to carry out the 1D-2D or 2D models before proposing the massive structures and analyst their impacts, before the construction, as those structures in any major rivers in worldwide, which may increase the flood risks or other adverse effect to the general public.

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Inventory Survey of Slope Failures in Sri Lanka

P. Yang, T. Nishikawa, H. H. Hemasinghe, and H. A. G. Jayathissa

Abstract The most common type of landslides in Sri Lanka is shallow, rapid-moving slope failures, particularly in response to an intense, short-duration storm. Different from reactivated landslides, the slope failures frequently occur on steep natural and artificial slopes without indications, thus posing a significant risk to population and property. An inventory survey of slope failures showed that the slope failures were related largely to slope steepness and slope height, and more than 80% of the slope failures occurred on slopes with a slope angle of 25–45° and a slope height of more than 5 m. A simple topographical model was developed based on the inventory survey results. The topographical model can be used to predict slope failure hazard areas and to prepare site-specific slope failure hazard maps for residential developments and land use planning decisions in sloping area.

Keywords Slope failure · Inventory survey · Topographical model · Site-specific hazard zonation

1 Introduction

Landslides are a frequent occurrence especially in the mountainous and hilly areas of the central highland of Sri Lanka (Bandara & Weerasinghe, 2013). Since 2003 Sri Lanka has increasingly suffered from severe landslide disasters, due to largely increasing improper land use management and new developments onto sloping lands and existing landslide areas in addition to unfavourable geological and geomorphologic settings and heavy rainfalls (DMC, 2007; Draft Manual on Site-specific Landslide Hazard Zoning, 2020; Petley et al., 2005). Landslide disasters in Sri Lanka have not only caused significant damages to property and loss of life, but also presented great problems in development and land use planning.

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Hence, an international assistant project—Technical Cooperation for Landslide Mitigation Project in the Democratic Socialist Republic of Sri Lanka, which was funded by Japan International Cooperation Agency (JICA), was implemented from September 2014 to September 2018, in response to the request of Sri Lankan government. This technical cooperation project concentrated on technology transfer on the design and construction of structural measures against landslides. Subsequently, a joint project between JICA and NBRO—Project for Capacity Strengthening on Development of Non-structural Measures for Landslide Risk Reduction (SABO Project) was commenced in February 2019 and will be completed in December 2021. This joint project focuses mainly on non-structural measures to strengthen NBRO's capacity in the implementation of non-structural measures for landslides, mainly with three outputs: (1) Capacities to conduct site specific hazard mapping and risk assessments; (2) Capacities to develop landslide early warning system at local level; and (3) Capacity to apply risk assessments of landslide disasters to land use planning and development standard (Koike et al., 2019).

In order to achieve the above-mentioned objectives and outputs, identifying and mapping site-specific landslide prone-areas and estimating their paths and runouts are an important first step not only for the development of landslide hazard and risk assessment method but also for the incorporation of landslide risk into land use planning. NBRO developed a landslide susceptibility methodology for landslide hazard zonation mapping under the Landslide Hazard Zonation Mapping Project (LHMP), which was implemented between 1986 and 1995 to study and identify the distribution of landslide potential in the central highlands (Manual on field mapping, 1995; Manual on landslide hazard zonation, 1995). A total of 205 landslide hazard zonation map sheets covering 8200 km^2 at 1:10,000 scale were prepared according to these manuals. The relative landslide susceptibility shown on the hazard zonation maps effectively discriminates relative landslide hazard at regional level. These landslide hazard zonation maps have been widely used as a planning tool to incorporate the degree of landslide hazard into development and human settlement planning at a regional level (Arambepola & Weerasingh, 1998). However, the existing mapping methodology cannot be used to locate and identify site-specific landslide prone-areas and their affected areas for making hazard and risk assessment at site-specific level. For example, in planning resettlement, the existing mapping methodology cannot be used to identify residential houses to remove them from individual landslide-prone area and its runout.

Landslides are a geomorphological process and directly affect the ground surface. The best indicator of landslide hazard is the evidence of past landslide movements, and therefore, remote-sensing techniques, such as aerial photography, satellite imagery, LiDAR imagery and radar imagery, have been widely used to detect and locate individual landslide prone area—previous and active landslide topographies by interpreting the changes in the form, position or appearance of the topographic surface (Blais-Stevens, 2008; Rib & Liang, 1978; Schulz, 2004).

Most landslides in Sri Lanka are first-time, shallow, fast-moving slope failures, either on steep natural or cut soil slopes (Draft Manual on Site-specific Landslide Hazard Zoning, 2020). Such slope failures are usually triggered by heavy rainfall without warning and ground indications. Compared with reactivated landslides, slope failure hazard areas are generally difficult to identify and detect by remote-sensing techniques. This is because their small size and shallow depth may be below the threshold for topographical interpretation. Consideration could be also given to slope failure scars on soil hillslopes which can be quickly covered by vegetation and subsequent erosion especially under humid tropical conditions, consequently making them recognizable after only a few months from their occurrence. Slope failures generally go unrecognized until damages are incurred, and thus have a higher potential to cause sudden, catastrophic damage to human life, infrastructures and residential houses.

This study focuses mainly on identifying areas subjected to fast-moving slope failures and analysing their runouts based on the inventory survey of recently occurred slope failures to develop a simple topographical model for predicting and mapping slope failure hazard areas and their affected areas. The developed topographical model may be used as an administrative tool to make rapid slope failure hazard assessment and to further guide development and land use planning in slope failure hazard areas.

2 Survey Method and Data Collection

2.1 Methodology

NBRO began constructing a landslide inventory database in 1980s. The database mainly contains known landslide locations and some associated data. However, the existing database is insufficient to make inventory statistical analysis for achieving the purpose of this study, and therefore the existing inventory record sheets were improved to provide an applicable database corresponding to the different types of landslides. Major landslide categories and items in the inventory record sheets include (1) Basic data on location, occurrence date/time/Inspection date, etc.; (2) Landslide occurrence data on geometry, size/dimension, activity, movement type, etc.; (3) Geo-environmental data on geological and topographical settings, land use, land cover, etc.; and (4) Detailed information on damages, such as human loss and property damage; and (5) Countermeasures for risk reduction, for example, prevention measures prior to disaster, and emergency and restoration measures after disasters.

The inventory survey was conducted through data collection from previous landslide events, satellite- and photo-interpretations and field survey, by the following procedure:

(a) To collect all reports of previous landslide events, as listed in Sect. 2 Data Source below, and then review them and obtain relevant data and information of landslide events, which were necessary for this study. For each major category and item, relevant data and information from each landslide event were compiled in the improved inventory record sheets and a Microsoft Excel spread sheet to facilitate inventory statistical analysis.

(b) To supplement the above-mentioned inventory record sheets and spread sheet through satellite- and photo-interpretations as well as geological and topographical analysis, when the satellite images, aerial photos, and geological and topographical maps were available. In addition, a satellite image-derived 10-m DEM (digital elevation model) was used to gather the relevant topographic data of each landslide event site.

(c) To select slope failure event sites following the type of landslides and the availability of data of landslide events collected for further field surveys. The purpose of field survey for the selected slope failure event sites was to further supplement and confirm inventory record sheets and spread sheet. The field survey, together with interview with local people, was carried out with some simple geological field equipment and tools such as geological hammer, compass-clinometer, handheld GPS, tape measure, and distance meter. In addition, the selected slope failure event sites were manually mapped onto the 1:20,000 scale satellite images.

2.2 Data Source

Data used in this study, as summarized in Table 1 below, are obtained from the following sources:

(a) Data Source 1: Past disaster record reports of more than 3000 disaster events occurred from 1976 to 2018, collected by NBRO, including slides, cutting failures, debris flows, rock falls, subsidence, etc.

(b) Data Source 2: Landslide Disaster May 2017—Damages & Loss Assessment, prepared by NBRO, including 35 slide and slope failure events occurred in 2017.

(c) Data Source 3: Reduction of Landslide Vulnerability by Mitigation Measure Projects—Cost Benefit Analysis, prepared by NBRO, in October 2018, including 50 slide and slope failure events.

As indicated in Table 1 above, all pertinent data cannot be collected and obtained from Data Source 1, and therefore, all data used for this study came from the slope failure events selected from Data Sources 2 and 3. Consequently 60 slope failure events occurred in 2017 and 2018 were selected for this study.

2.3 Terminology

It is necessary to clarify the terminology used to avoid any confusion. In this study landslide is a broad term referring to the downslope movement of rock, soil, or both under the influence of gravity (Cruden & Varnes, 1996), and it mainly includes slide, slope failure, debris flows, and rock fall (Draft Manual on Site-specific Landslide Hazard Zoning, 2020). Slope failures are shallow, fast-moving types on steep

Table 1 Summary of data sources collected

Data source	No. of landslide events	No. of selected slope failure events	Ranges and availability of data
1	3,215	0	– Location and coordinate – Occurrence date/time – Event description – Geological data
2	35	28	– Location and coordinate – Occurrence date/time – Detailed event description – Geological and topographical maps, satellite images (post-event) – Dimension and geometry of landslide event areas – Damage conditions – Etc.
3	50	34	– Location and coordinate – Occurrence date/time – Detailed event description – Geological and topographical maps, satellite images (post-event) – Geological survey reports, – Dimension and geometry of landslide event areas – Damage conditions – Etc.

soil slopes, either natural or artificial, generally with a relatively small volume of displaced mass. In addition, standard methods, as proposed by WP/WLI (1990; 1991; 1993), have been adopted to describe the basic types of landslide, their features and dimensions.

3 Results and Discussion

3.1 Topographical and Geological Attributes

Topographically and geologically, steeper slopes tend to be less stable when other conditions are identical. Figure 1 shows the frequency distribution of slope steepness and slope failure potential. The results attest that the number of slope failures tends to greatly increase when slope angles increase until a limiting steepness of 25° is achieved. They also indicate that slope angles between 25 and 45° are the most

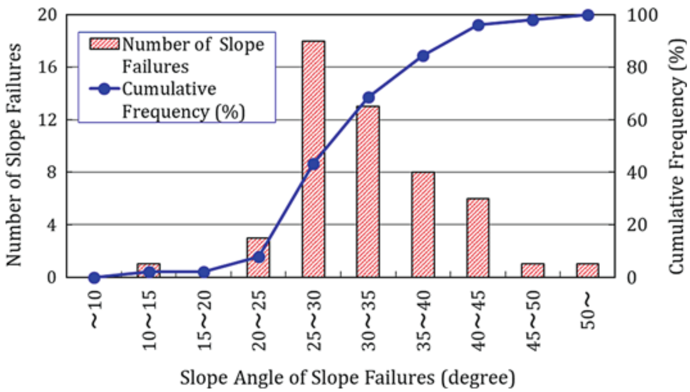

Fig. 1 Frequency distribution of slope angle in soil slope failures

frequent to fail, accounting for more than 80% of the total number of the past slope failures. The results further show that the very steep slopes of more than 45° and the very gentle slopes of less than 20° are less disturbed by slope failures. The inventory survey collected past slope failures occurring on soil hillslopes, a steep slope of more than 45° may have previously failed or be bedrock escarpment without soil cover.

Many studies have attempted to quantify the relationship between slope steepness and slope failure or landslide hazard (Gao, 1993; Fernandes et al., 2004; Larsen & Torres-Sanchez, 1998; Robison et al., 1999). Fernandes et al., (2004) found that most landslides occurred on slopes with a slope angle of 18.7 to 37.0°, while Robison et al., (1999) indicated that most of the landslides were initiated where slope steepness was over 70% (approximately 35°). The results (Fig. 1), along with review of relevant literatures suggest that the threshold slope steepness is present for initiating landslides and slope failures. The threshold slope steepness also depends upon regional meteorological conditions and slope materials, and this leads to different slope steepness relating to the initiation of slope failures in different regions.

Similarly, Fig. 2 shows the frequency distribution of slope height and slope failure potential. The results indicate that slope failures are related largely to slope height and that slope failures occurred almost on slopes with a slope height of over 5 m and mostly between 5 and 35 m. Yamakoshi et al., (2018) reported a similar relationship between slope height and slope failure potential.

Slope landform also has a significant effect on slope stability (Benda et al., 2000). Figure 3 shows the frequency distribution of slope landforms of soil slope failures, where slope landform is roughly divided into three types, as shown in Fig. 4. Concave slopes generally tend to develop thicker colluvial soils and are also the locations of concentrated drainage, and therefore, are more susceptible to slope failures than straight (planar) and convex (divergent) slopes.

Slope failures in Sri Lanka occur mostly in colluvial soils and partly in residual soils or along the boundary of soil and weathered rocks, as shown in Fig. 5. Geological and geotechnical properties of slope materials can exert important control on the

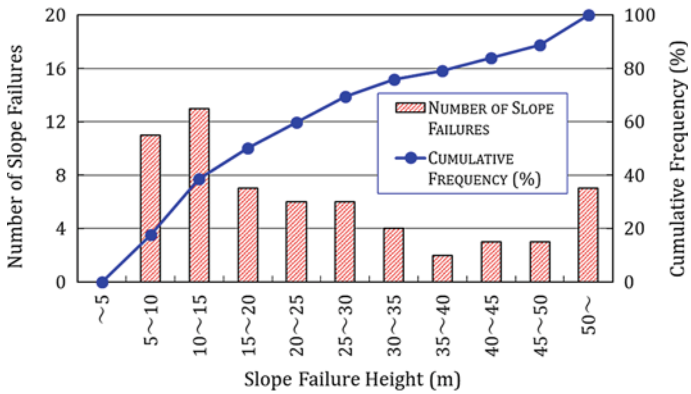

Fig. 2 Frequency distribution of slope height of soil slope failures

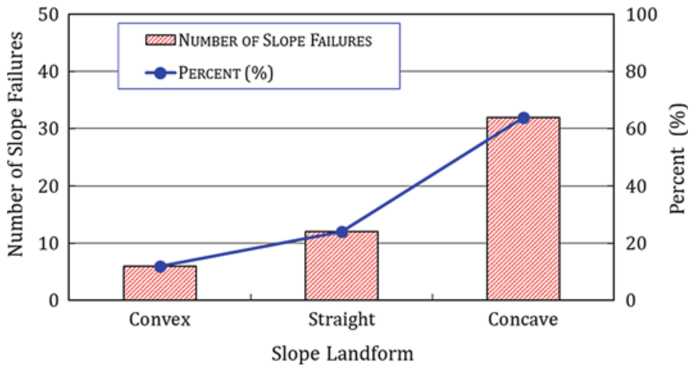

Fig. 3 Frequency distribution of slope form of soil slope failures

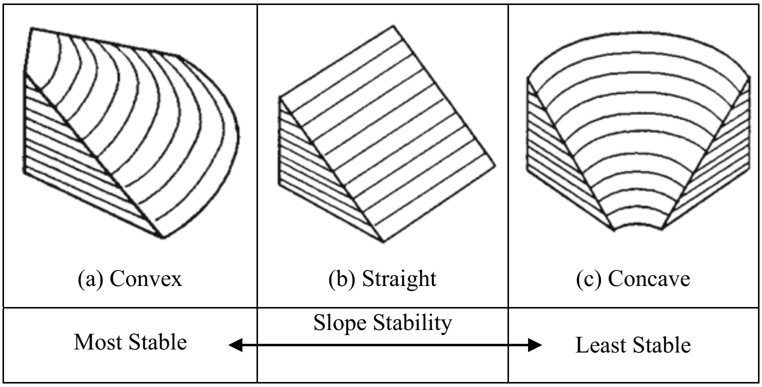

Fig. 4 Schematic of convex, straight and convergent topography (modified from Benda et al., 2000)

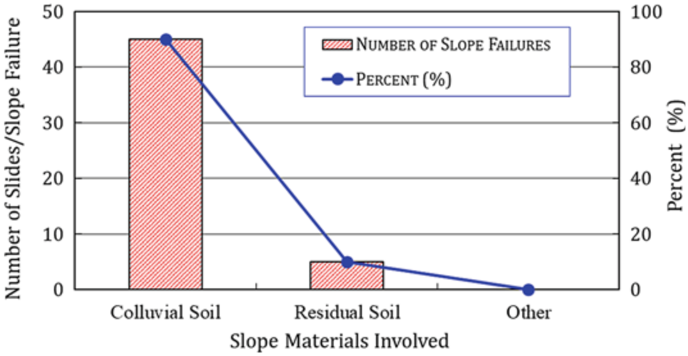

Fig. 5 Type of slope material involved in slope failures

stability of slopes. Colluvial soils are generally formed by weathering and erosion of rock and soil, and mainly associated with movement and deposition downslope by gravity, and therefore are typically loosely consolidated soils. Such soils have relatively low shear strengths and are susceptible to slope failures or landslides as a result of greatly decreased shear strengths and sharply increased groundwater levels during heavy rainfall.

In addition, the inventory survey shows that these colluvial soils involved in the surveyed slope failures can be further subdivided into sandy and gravelly soils. The sandy and gravelly soils have the estimated average friction angles of about 25 to 35°, and of 35 to 40°, respectively (Manual for Highway Earth Works, 2005). This further indicates that a steep colluvial soil slope with a slope gradient of 25° or more is likely to become unstable especially as excessive pore water pressure increases during heavy or intense rainfall.

3.2 Runout Distance of Slope Failure

When a slope failure occurs, its runout or reaching distance is also one of the major parameters for slope failure risk assessment and preventive structural measure design. A longer runout has more severe risk to human life and property. Figure 6 gives the relationship between the slope height and the reaching distance of slope failures. The results indicate that the reaching distances have a good correlation with the heights of slope failures (L4 = 0.5H).

Figure 6 also shows that the reaching distances are almost within twice the height of slope failures (L4 = 2H), but with a limit of about 100 m. In addition, some slope failure events showed longer runout distances, and this may be because such slope failures were transferred into debris flow.

Figure 7 shows the frequency distribution of ratio of the widths after and before slope failures occurrence. The results show that the width of displaced mass is mostly

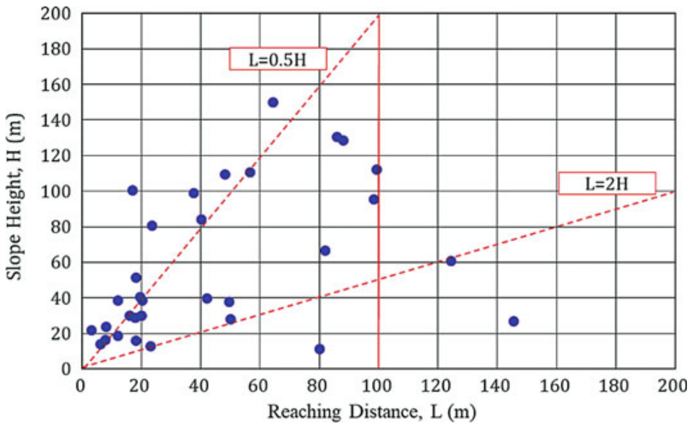

Fig. 6 Relationship between slope height and reaching distance

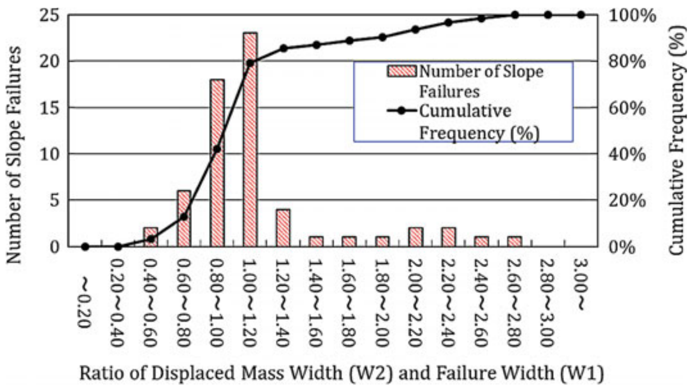

Fig. 7 Frequency distribution of displaced mass width/failure width

the same as that prior to failure and movement, further suggesting that slope failures, once occurring, mostly cause less or no lateral expansion or extension.

3.3 Simplified Topographical Model

No reliable method has been developed to locate and identify area subject to slope failures at local and site-specific scale. In order to develop a simple and practical method for identifying slope failure hazard areas as well as their affected areas, two issues need to be understood based on the inventory survey results. The first one, relating to the initiation area, is how to identify the conditions under which slope

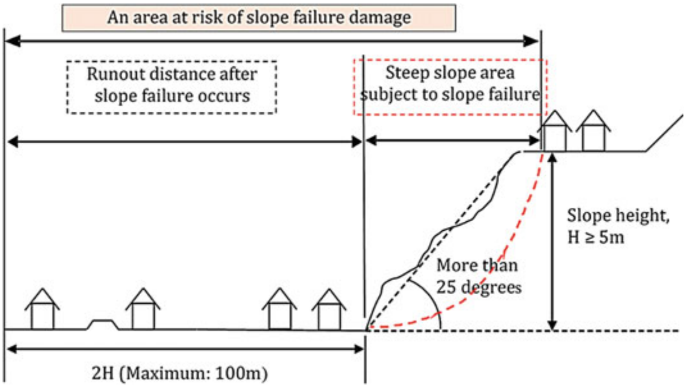

Fig. 8 Schematic of simplified topographical model

failures are likely to occur. The second one, relating to the affected area, is where and how far it will reach once the slope failure occurs.

The potential for slope failures is dependent on many factors, including slope height, slope steepness, slope landform, type and shear strength of the underlying geologic materials, as well as meteorological conditions. The above analysis and discussion on topographical and geological attributes as well as on runout distances suggest the following threshold conditions for locating slope failure hazard area including its affected area, as illustrated in Fig. 8.

(a) Steep soil slopes have a slope gradient of 25 to 45° and a slope height of over 5 m; and
(b) The maximum runout distance set is less than twice the height of slope failure with a limit of 100 m.

In Japan, a similar topographical model was proposed under the Sediment-Related Disaster Prevention Act enacted in 2001 as an administrative tool to locate and manage slope failure hazard areas (Guidelines and exposition for producing sediment disaster hazard maps, 2005). The topographical model has been widely used to quickly delineate an area prone to sediment-related disasters including steep slope failures, in order to regulate new development for housing and other purposes, to promote relocation of existing houses, and to develop early warning systems for residents within the identified hazard areas.

4 Conclusions

The inventory survey provided important information for understanding the process, occurrence mechanism, spatial distribution and topographic and geological attributes of slope failures. The following concluding remarks can be drawn by the inventory survey.

(a) Slope failures are major and frequent hazards in Sri Lanka. They occur mostly on steep slopes of colluvial and residual soils during heavy rainfall. Many of the steep, concave hillslopes covered with thick colluvial soils are the sites of highly potential slope failures.
(b) Slope failures are related strongly to slope steepness and slope height, and their runout distances to the height of slope failure areas.
(c) The developed topographical model can be used to quickly locate slope failure hazard areas at site-specific level and to estimate their runouts if they occur, with the following threshold topographical conditions:

  – A steep soil slope having a gradient of 25 to 45° and a height of 5 m or more; and
  – An area located within twice the height of a steep slope, but less than 100 m, from the bottom of a steep slope.

(d) Identification of slope failure hazard area and estimation of associated runout distance are the first step towards an analysis and assessment of the potential hazard and risks to population and infrastructure as well as new development and land use planning.

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Plant Selection Criterion for Nature-Based Landslide Risk Management

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Abstract Nature-based landslide risk management (NBLRM) involves use of plants in mitigating slope instabilities. These interventions provide sustainable and cost-effective approaches for landslide disaster risk reduction. At present in Sri Lanka, attempts are made to incorporate beneficial services of plants species in implementing landslide risk mitigation measures. However, a guiding framework in selecting appropriate plant species for landslide prone sites had not been available. Effectiveness of plants for nature-based landslide risk management mainly depends on the root architecture and its mechanical properties. Ecological and socio-economic significance of plant species also play a major role in selection of plants, especially when the nature-based solutions are to be applied in disturbed landscape. After conducting a systematic literature review, four key factors were identified. Namely, Root strength characteristics, Hydrological significance, Ecological significance and Economic value. Performance of each species under respective factor was assigned a score, based on a scale of 4 depending on their suitability for stabilizing soil on slopes. A cumulative index greater than 2 and the compatibility with the eco-climatic region were considered when selecting plant species for landslide prone sites. The proposed plant selection criterion was used as a tool to rank 33 candidate plants collected from landslide prone areas in determining suitable species for NBLRM in Sri Lanka.

Keywords Nature-based · Landslide · Plant Selection

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1 Introduction

Nature-based landslide risk management is a novel technique which is at present gaining popularity in Asian countries such as Nepal, Bangladesh, Thailand, Hong Kong etc. The techniques involve use of plant species to mitigate slope instabilities. They are seen by the scientific community as interventions which provide sustainable, cost effective and ecologically and environmentally friendly approaches for landslide disaster risk reduction. Arce-Mojica et al. (2019) mentioned that the importance of nature-based solutions is highlighted in the Sendai Framework for Disaster Risk Reduction 2015–2030 as an effective technique to reduce disaster risk, adapt to climate change and strengthen community resilience.

These interventions can be comprised only of plants or can be implemented with conventional engineering measures as hybrid solutions. Such solutions will improve the effectiveness of engineering measures in mitigating slope instabilities. Further, nature-based techniques will provide a better aesthetic outlook for already implemented engineering measures allowing them to be blended with the surrounding environment.

At present in Sri Lanka, attempts are made to incorporate beneficial services of plant species in implementing landslide risk mitigation measures (Balasuriya et al., 2018; Bandara & Jayasingha, 2018; World Bank, 2019a). However, a guiding framework in selecting plant species for landslide prone sites had not been available. Selection of suitable plant species to compose effective nature-based landslide risk management strategies needs to be carried out according to a systematic approach. There are plant selection frameworks developed in other countries such as China and Spain (De Baets et al., 2009; Ghestem et al., 2014) to guide practicing professionals in the choice of plant species.

This paper discusses a possible Plant Selection Criterion that could be adopted in the Sri Lankan context in order to effectively implement nature-based landslide risk management strategies.

2 Role of Plants in Mitigating Slope Instabilities

Use of plant species for erosion control has been practiced in many parts of the world for centuries. However, the application of plants for prevention and reducing the impacts of landslides is yet new to the world. Its knowledge is continuously evolving.

Research studies carried out to-date have listed the positive enhancements offered by plant species in mitigating slope instabilities (Fatahi et al., 2010; Mulyono et al., 2018; Pallewattha et al., 2019). They are:

1. Soil reinforcement by plant roots;
2. Protection of soil surface from erosion and gullying as roots bind soil particles;

3. Dissipation of excess pore-water pressure in soil via root water uptake and evapotranspiration;
4. Establishment of sufficient matric suction to increase the soil shear strength via root water uptake;
5. Rainfall interception via the foliage.

Numerous case studies have been conducted by the scientific community in evaluating the degree of slope stability improvement due to the presence of plant species. For instance, Viet et al. (2016) conducted an assessment on the contribution of vegetation cover to slope stabilization in a small watershed in Jinbu-Myeon, Pyeongchang-gun, Republic of Korea. The analyzed results had shown that vegetation cover had provided an additional soil cohesion of 3.8 kPa. Ali et al. (2012) conducted a slope stability assessment using data from a mature lime tree from United Kingdom. Their results indicated that the Factor of Safety against failure could increase by more than 8% when including the influence of a mature tree located at toe of a slope. Further, they indicated that the mechanical contribution offered by vegetation is much greater than the influence of hydrological effects on the soil strength.

Plants also exhibit undesirable impacts on slope stability. They are: Roots increase permeability of soil, leading to increased infiltration capacity; depletion of soil moisture can lead to the formation of desiccation cracks in soil, resulting in higher infiltration capacity; and plants (mainly trees) exposed to wind exerts dynamic forces on the slope (Gray & Sotir, 1996; Greenwood et al., 2004; Mulyono et al., 2018).

3 Selection of Plant Species

Saifuddin and Normaniza (2016) mentioned that plant communities can be divided into four categories, namely, grass, herb, shrub and trees. In addition, there are creeper plants which grow upon the ground surface or any other surface sending out rootlets from its stem. Likewise, there are wide range of plant types which vary from few millimeter high small creepers to trees with heights up to 50 m.

Selecting plant species for nature-based applications needs to be done via a multi-disciplinary approach. Lewis et al. (2001) mentioned that such approaches require the views of several disciplines and is often a collaborative exercise of soil scientists, hydrologists, ecologists, engineering geologists, maintenance personnel, civil engineers, and landscape architects. Thus, selection of suitable plant species in order to achieve desired stabilization objectives for a particular site, require a careful balance of considerations.

Different plant species offer, above mentioned positive enhancements to varying degrees depending on bioengineering characteristics possessed by the individual species. Gray and Sotir (1996) indicated that woody vegetation has stronger and deeper roots than herbaceous plants & grasses and provides greater mechanical reinforcement and buttressing action at depth. Grasses and herbaceous vegetation grow close to the surface and provide a tight, dense ground cover. They tend to be effective in intercepting rainfall and preventing surficial erosion. Shrubs do not have deep roots as trees and hence, they provide less buttressing restraint. However, shrubs have less above ground biomass and exert less surcharge on a slope.

It would be better if a plant selection method can be composed of easily measurable plant traits with a geotechnical basis since the main objective is slope stabilization. Ecological variability of plants, soil and climate factors shall also be considered in selecting a plant for a given site. Further, if nature-based techniques are to be applied in arable land, the socioeconomic context of the particular site with landslide threat need to be taken into account in order to see the possibility of providing benefits from the proposed plants at that site to the community living nearby.

Landslide risk management professionals would immensely benefit from an effective plant selection method once adequate evaluations of the candidate plants have been carried out.

4 Plant Selection Frameworks Available in Literature

Studies from China and Spain had utilized plant traits (below & above ground) to evaluate plant species to fix slope instabilities and reduce soil erosion.

Ghestem et al. (2014) developed a plant selection framework for fixing soil on steep slopes in western Yunan China. The framework was based on below ground plant traits (Table 1). They had evaluated several plant species that were not invasive and were of having economic value to local population via the developed plant selection framework. Further, they demonstrated that it was unlikely that any one plant species possesses an entire suite of root traits necessary to efficiently stabilize a slope regarding shallow landslides. They suggested the use of mixtures of species, as well as a targeted spatial use of species in particularly fragile hotspots.

Table 1 List of desirable plant traits (below and above ground)

Below ground plant traits	Above ground plant traits
High root density (high root area ratio) (De Baets et al., 2009; Ghestem et al., 2014)	High stem density (De Baets et al., 2009)
High root tensile strength (De Baets et al., 2009; Ghestem et al., 2014)	High sediment and organic debris obstruction potential (De Baets et al., 2009)
High resistance in bending of coarse roots (Ghestem et al., 2014)	High Plant stem stiffness (De Baets et al., 2009)
Short deformation of roots (Short ultimate tensile strain) (Ghestem et al., 2014)	
High metabolism (High root nitrogen content) (Ghestem et al., 2014)	
High longevity (High cellulose content) (Ghestem et al., 2014)	

De Baets et al. (2009) presented a methodological framework to select plant species for controlling rill and gully erosion and its application to 25 plant species, representative for a semi-arid Mediterranean landscape in southeast Spain. They had taken into account both above and below ground plant traits in evaluating the suitability of plant species (Table 1).

Above described selection frameworks have not considered the hydrological significance of a plant which is represented by its evapotranspiration and rainfall interception capacity.

Yen, cited in Saifuddin and Normaniza (2016) classified root architecture of plant species into five types, namely, H, R, V, VH and M. From the survey of previous studies, they mentioned that the H- and VH-root types had been found to be suitable for soil reinforcement and slope protection. The M-type is beneficial in controlling soil erosion (Table 2). Saifuddin and Normaniza (2016) further suggested that plant species having H- and VH-root type will better reinforce soil in the middle of the slope. Species having M-type roots will be more suitable at the top or toe of the slope.

Table 2 Description of root architecture of plant species (Yen, cited in World Bank, 2019b)

Root type	Spatial layout
H Type: Maximum root development occurs at moderate depth, with more than 80% of the root matrix found in the top 60 cm; most of the roots extend horizontally and their lateral extent is wide	
VH-type: maximum root development is moderate to deep but 80% of the root matrix occurs within the top 60 cm; there is a strong tap root but the lateral roots grow horizontally and profusely, and their lateral extent is wide	
M-type: maximum root development is deep but 80% of the root matrix occurs within the top 30 cm; the main roots grow profusely and massively under the stump and have a narrow lateral extent	
R-type: maximum root development is deep, with only 20% of the root matrix found in the top 60 cm; most of the main roots extend obliquely or at right angles to the slope and their lateral extent is wide	
V-type: maximum root development is moderate to deep; there is a strong tap root but the lateral roots are sparse and narrow in extent	

5 Methodology Adopted in Composing the Framework

5.1 Systematic Literature Review

A systematic literature review was conducted to identify key factors from which plant species can be evaluated based on their suitability to mitigate landslide risk. Collected information was further refined by additional inputs and ideas from practitioners, scientists, and engineers working in the field of landslide risk management. In addition, information is collected on natural vegetation types present in landslide prone areas of Sri Lanka. Generally, the landslide prone areas are overlapped with wet and intermediate zones in the country.

Socioeconomic status of landslide prone districts were also studied. Perera et al. (2018) mentioned that agroforestry makes a significant contribution to the socio-economic system of rural communities in Sri Lanka and in general, they are located on slopes, of which most are vulnerable to landslides.

5.2 Application of the Developed Plant Selection Criterion to a Sample of Preselected Species

Based on the newly developed plant selection criterion, several plant species were selected from land-slide prone areas of Sri Lanka. The selected species were identified from natural landscapes in the hill country districts as well as from Agro–forests/Kandyan home gardens which is a traditional practice of gardening practiced in hill country districts of Sri Lanka.

6 Proposed Plant Selection Criterion

The effectiveness of plant species for mitigation of landslide risk depends mainly on plant root architecture and its mechanical properties such as the root tensile strength. Some plants are better suited in mitigating slope instabilities, but they may have low ecological/economic significance and would be of less beneficial to the environment and community living nearby. Hence, the selection of suitable plant species to manage landslide risks requires a better balance within a multi criteria approach.

This paper proposes a plant selection criterion which is composed of four key factors that can be adopted in the Sri Lankan context of landslide risk management.

6.1 Key Factors

Root strength characteristics

Generally, soil apparent cohesion increases with increasing root density and root tensile strength. Root density decreases with depth of root penetration. This implies that plant species can have its greatest effect close to the ground surface where the root density is generally higher. The type of root system also influences in improving the slope stability. Research studies suggested that plant species having H- and VH-root types (Table 2) are suitable for soil reinforcement and slope protection. Further, plant species having roots which extend into greater depths would be more efficient in arresting slope instabilities.

Hydrological significance

Evapotranspiration process and rainfall interception by the foliage are the two main phenomena that contribute to lower the development of excessive pore-water pressure beneath the ground surface during heavy precipitation events. Plant species having high evapotranspiration capacities and a widespread canopy will be excellent candidates in mitigating slope instabilities.

Ecological significance

It is essential to have a broad understanding of the natural vegetation cover and the way in which it closely reflects the interaction of natural conditions prevailing at any given location.

Generally pioneer plant species grow and propagate well in degraded lands strengthening the soil surface layers. On the other hand, introducing plant species that are not commonly found in the interested site location or introducing non-native species may lead to cause adverse effects to the site as well as its surrounding vegetation. A plant may have excellent bioengineering characteristics but if it is an invasive plant for a particular region, the overall effectiveness of that particular species may not be beneficial.

Economic value

In Sri Lanka, a major portion of the areas that have already experienced landslides and areas that have been identified as landslide hazardous areas are productive lands. Hence, it would be better if the land can be used for continued production, particularly for agriculture if the land supports livelihood of nearby communities. Perera et al. (2018) had found that agriculture relate activities are a major source of income for the rural community in many landslides affected areas in Sri Lanka. Therefore, an economic condition in the selection criteria that can recognize the value of the plant to be established would provide a win–win situation where nature-based solutions protect the rural livelihood while contributing to manage the landslide risk effectively.

Table 3 Scaling of the key factors

Score	Root strength characteristics	Hydrological significance	Ecological significance	Economic value
0	Shallow and low strength	Insignificant	Invasive	Unimportant
1	Shallow and medium strength	Low	Introduced, non-invasive	Indirect only
2	Moderate depth and medium strength	Moderate	Introduced, non-pioneer, agricultural	Indirect and low direct benefits
3	Moderate depth and high strength	High	Native, pioneer, agricultural	High indirect and direct benefits
4	Deep and high strength	Very high	Native/ endemic, pioneer, agricultural	Very high indirect and direct benefits

6.2 A Scale for Plant Species Evaluation

In order to evaluate different plant species categories (grasses, herbs, shrubs and trees) and rank them according to their suitability for nature-based landslide risk management, each factor was given a score based on a scale of four. Table 3 presents the scaling of the key factors.

A cumulative index for an individual plant species based on a scale of 4 was calculated using Eq. (1)

$$Cumulative\ index = \frac{\sum(Root\ Strength + Hydrological + Ecological + Economic)}{4} \tag{1}$$

A cumulative index greater than 2 and the compatibility with the eco-climatic region were considered when selecting plant species for landslide prone sites. Figure 1 presents the developed plant selection criterion as a schematic diagram.

6.3 Application of the Proposed Plant Selection Criterion to Preselected Species

Commonly found thirty-three plant species from landslide prone area were identified and indexed based on newly developed plant selection criterion. The selected list included six types of grasses six types of shrubs and twenty-one types of trees.

The species were evaluated against the four key factors based on information obtained from previous literature, field observation and discussion with local people. Scores were given under each factor as given in Table 3. Finally, a cumulative index for each individual species was calculated using Eq. (1).

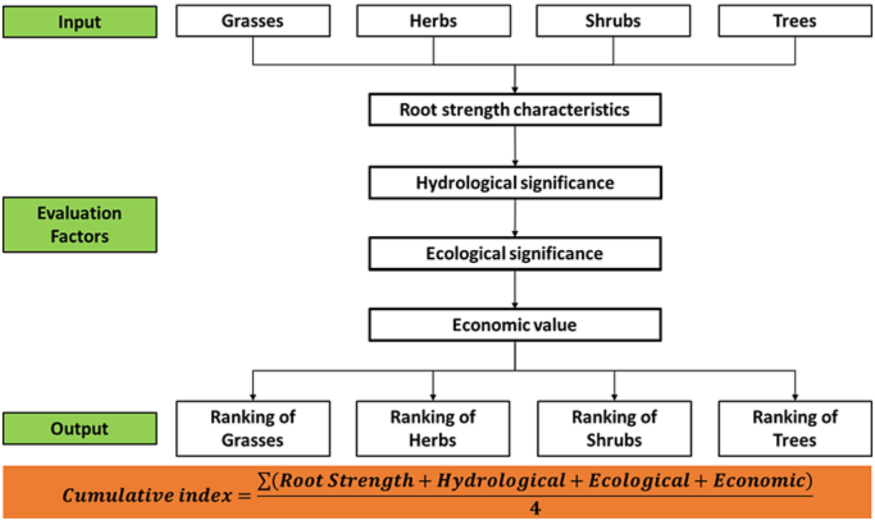

Fig. 1 Proposed plant selection criterion

Among the thirty three plant species, those which obtained highest numerical index are presented under the categories of grasses, shrubs and trees in Tables 4, 5 and 6 respectively.

Among the grass species *Arundo donax* (Wild cane "Bata") and *Bambusa vulgaris* (Common bamboo) obtained the highest score. They both possess high to medium evapotranspiration capacity and dense fibrous roots which penetrate to moderate depth. *Jatropha curcas* (Physic nut "Edaru"), *Vitex negundo* (Chaste tree "Nika") and *Melastoma malabathricum* (Malabar melastome "Maha bovitiya") were the best performers among the shrubs. *Michelia champaca* (Champak "Ginisapu"), *Macaranga peltata* ("Kenda"), *Trema orientalis* (Charcoal tree "Gaduma") and *Theobroma cacoa* (Cacoa) were the best candidate trees to be used in nature-based landslide risk management practices. *Macaranga peltata* ("Kenda") and *Trema orientalis*

Table 4 Suitable grasses

Scientific name	Common name	Vegetation architecture	Root strength	Hydrological	Ecological	Economic	Cumulative index
Arundo donax	Wild cane	Tall clumping grass	4	4	3	3	3.5
Bambusa vulgaris	Common bamboo	Densely tufted culms	3	3	4	4	3.5
Chrysopogon zizanioides	Vetiver grass	Medium size perennial grass	4	3	4	2	3.3

Table 5 Suitable shrubs

Scientific name	Common name	Vegetation architecture	Root strength	Hydrological	Ecological	Economic	Cumulative index
Jatropha curcas	Physic nut	Small to medium shrub	4	4	3	3	3.5
Vitex negundo	Chaste tree	Small to medium shrub	4	3	4	3	3.5
Melastoma malabathricum	Malabar melastome	Small shrub	4	3	4	3	3.5

Table 6 Suitable trees

Scientific name	Common name	Vegetation architecture	Root strength	Hydrological	Ecological	Economic	Cumulative index
Theobroma cacao	Cacoa	Medium size tree	4	4	4	4	4
Gliricidia sepium	Gliricidia	Medium size tree	4	4	3	4	3.8
Macaranga peltata	"Kenda"	Medium to large tree	4	4	4	3	3.8
Trema orientalis	Charcoal tree "Gaduma"	Medium to large tree	4	4	4	3	3.8
Michelia champaca	Champak	Large tree	4	4	3	4	3.8

(Charcoal tree "Gaduma") are referred as pioneer species and grow well in degraded lands subjected to landslides.

Results of all the thirty-three plant species considered under the study are given in Annex 1.

7 Conclusions

The proposed plant selection criterion (Fig. 1) will be greatly beneficial for landslide risk management professionals in Sri Lanka to identify suitable plant species when implementing nature-based landslide risk management strategies. This criterion will be a very useful tool in ranking and determining suitable plant species for nature-based landslide risk management techniques. The expert knowledge and input of a botanist or an ecologist is recommended at the time of collection of information under each of the listed key factors of the selection criterion, as this would enable a very effective plant species evaluation for nature-based landslide risk management.

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Annex

See Annex Table 7.

Table 7 Evaluation of thirty-three selected plant species based on the proposed plant selection criterion

#	Type	Scientific name	Common name in English	Plant type and structural characteristics	Root strength	Hydrological significance	Ecological significance	Economic value	Cumulative score
1	Grass	*Cymbopogon citratus*	Lemongrass	Medium size perennial grass	3	2	3	3	2.8
2	Grass	*Chrysopogon zizanioides*	Vetiver grass	Medium size perennial grass	4	3	4	2	3.3
3	Grass	*Chrysopogon nardus*	Citronella	Medium size perennial grass	3	2	4	3	3.0
4	Grass	*Bambusa vulgaris*	Common bamboo	Densely tufted culms	3	3	4	4	3.5
5	Grass	*Imperata cylindrica*	Cogon grass	Medium size grass	4	2	0	1	1.8
6	Grass	*Arundo donax*	Wild cane	Tall clumping grass	4	4	3	3	3.5
7	Shrub	*Hibiscus tiliaceus*	Wild cotton tree	Medium to large shrub	4	4	2	1	2.8
8	Shrub	*Murraya paniculata*	Orange jessamine	Small to medium shrub	3	2	3	2	2.5
9	Shrub	*Jatropha curcas*	Physic nut	Small to medium shrub	4	4	3	3	3.5
10	Shrub	*Vitex negundo*	Chaste tree	Small to medium shrub	4	3	4	3	3.5
11	Shrub	*Melastoma malabathricum*	Malabar melastome	Small shrub	4	3	4	3	3.5

(continued)

Table 7 (continued)

#	Type	Scientific name	Common name in English	Plant type and structural characteristics	Root strength	Hydrological significance	Ecological significance	Economic value	Cumulative score
12	Shrub	*Coffea arabica*	Coffee	Medium size shrub	3	3	3	4	3.3
13	Tree	*Acacia catechu*	Cutch Tree	Small to medium tree	4	2	3	2	2.8
14	Tree	*Michelia champaca*	Champak	Large tree	4	4	3	4	3.8
15	Tree	*Bauhinia racemosa*	Bidi leaf tree	Medium to large tree	4	3	4	2	3.3
16	Tree	*Bauhinia purpurea*	Orchid tree	Medium to large tree	4	3	4	2	3.3
17	Tree	*Azadirachta indica*	Neem tree	Large tree	4	3	4	3	3.5
18	Tree	*Leucaena leucocephala*	White lead tree	Medium to large tree	4	3	3	4	3.5
19	Tree	*Peltophorum pterocarpum*	Yellow flame tree	Medium to large tree	4	3	4	2	3.3
20	Tree	*Pterocarpus indicus*	Prickly padauk	Large tree	4	3	3	3	3.3
21	Tree	*Wendlandia bicuspidata*	"Rawana Idala"	Small tree	4	3	4	2	3.3
22	Tree	*Eurya accuminata*		Small tree	4	3	4	3	3.5

(continued)

Table 7 (continued)

#	Type	Scientific name	Common name in English	Plant type and structural characteristics	Root strength	Hydrological significance	Ecological significance	Economic value	Cumulative score
23	Tree	*Macaranga peltata*	"Kenda"	Medium to large tree	4	4	4	3	3.8
24	Tree	*Trema orientalis*	Charcoal tree	Medium to large tree	4	4	4	3	3.8
25	Tree	*Glochidion moonii*		Medium to large tree	4	4	4	2	3.5
26	Tree	*Myristica fragrans*	Nutmeg	Medium size tree	4	3	4	4	3.8
27	Tree	*Eugenia caryophyllus*	Clove	Medium size tree	4	3	4	4	3.8
28	Tree	*Theobroma cacao*	Cacoa	Medium size tree	4	4	4	4	4.0
29	Tree	*Gliricidia sepium*	Gliricidia	Medium size tree	4	4	3	4	3.8
30	Tree	*Areca catechu*	Areca	Large and tall monocot tree	3	2	2	3	2.5
31	Tree	*Cinnamomum verum*	Cinnamomum	Medium size tree	4	3	4	4	3.8
32	Tree	*Dillenia indica*	Elephant apple	Medium to large tree	4	4	2	1	2.8
33	Tree	*Dillenia retusa*	Godapara	Medium to large tree	3	4	2	1	2.5

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Impact of Tsunami on Heterogeneous Economic Sectors: The Case of Sri Lanka

Sajeevani Weerasekara and Clevo Wilson

Abstract Although natural disasters can cause enormous destruction to a country's economy, there remains an unsettled debate on whether disasters bring similarly large negative impacts throughout heterogeneous sectors of an economy. The literature indicates that the consequences for the economy differ according to the magnitude of the disaster, although such findings are inconclusive when other variables such as the scope, scale, type of disaster, the type of economy, etc., are taken into account. On the one hand, natural disasters—such as a tsunami—may destroy a large number of human lives and much physical capital including R&D facilities and therefore have a negative impact on an economy's growth rate. On the other hand, such disasters may have a positive effect through rebuilding a superior infrastructure and the use of more advanced technology. In this paper, we explore whether the 2004 tsunami caused, in the three major sectors of Sri Lanka's economy—agriculture, industry and services—a similar negative impact in both the short and long run. We employed panel fixed effect, difference-in-difference (DID) and panel vector auto regression (exogenous) (PVARX) estimation methods. The results suggest that the effect on each economic sector differed widely. Although the impact was highly negative on all three economic sectors in the first year following the tsunami, the impact on the agricultural sector was comparatively greater and the recovery process was longer than the other sectors. Moreover, the results suggest that industrial and services sectors have actually experienced positive impacts over the long term as indicated by the increase in demand for reconstruction and "building back better" infrastructure after the disaster as well as the considerable inflow of aid and grants that were received for advancement of the industrial and services sectors.

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1 Introduction

At a time when the global climate change is becoming more pronounced, the frequency and magnitude of natural disasters will also continue to rise and prove to be a major impediment against sustainable development (see, for example, Zhang & Managi, 2020). Hence, for production processes, there needs to be far greater attention to pre- and post-disaster mitigation and management strategies. During the period from 1998 to 2017, disaster hit countries recorded direct economic losses of US$2908 Billion, of which climate-related disasters accounted for US$2245 Billion or 77% of the total. Based on this, many international organizations including the IMF, the World Bank and many research organizations, such as the Centre for Research on the Epidemiology of Disasters (CRED) highlighted that beginning from the early part of this century, exogenous shocks such as disasters could have a substantial negative impact on the growth, macroeconomic stability, debt sustainability and poverty of less developed countries. UNISDR (2015) has emphasized that "low-income countries are predominantly vulnerable to natural disasters compared to the developed countries and further, agriculture dependent countries are likely to suffer higher negative impacts than non-agricultural countries." Following these international research initiatives, a number of scholars have continued to explore the nexus between natural disasters and economic growth more deeply and in specific ways.

The 2004 tsunami proved to be the largest global disaster in recent history as it resulted in a death toll of about 282,000 and caused extensive damage in dozens of countries. According to Abbott (2004) as cited by Athukorala and Resosudarmo (2005), the previous deadliest tsunamis were the following (estimated death tolls are in parentheses): Indonesia, 27 August 1883 (36,000); Portugal, 1 November 1755 (30,000); Japan, 15 June 1896 (27,000); Japan, 21 May 1792 (14,000); and Japan, 27 March 1933 (3000). After the damage to Sri Lanka was assessed, the numbers recorded were 35,000 deaths, 500,000 made homeless and some 100,000 houses damaged (Brunet et al., 2008). Without doubt then, it was the biggest natural disaster to strike Sri Lanka. As per the past literature, the economic consequences of a disaster will likely differ according to the magnitude of the disaster (Emanuel, 2011; Keerthiratne & Tol, 2017; Klomp & Valckx, 2014; Zhou & Zhang 2021). However, the literature is inconclusive due to the variations in the scope and scale of disasters, the type of disaster, the type of economy (developed or underdeveloped), and area affected (national or regional) (Easterly & Kraay, 2000; McDermott et al., 2014; Noy & Nualsri, 2011). Natural disasters such as tsunamis may destroy a large amount of human and physical capital as well as R&D facilities and therefore, have a negative impact on the growth rate (Jacoby & Skoufias, 1997; Klomp & Valckx, 2014). On the other hand, replacing the existing technology with more advanced technology may have a positive impact on growth (Hallegatte & Dumas, 2009; Popp, 2006). Hence, investigating the impact of the tsunami on different economic sectors is important due to the severe disruption caused by major disasters to developing economies.

Accordingly, there is an unsettled debate on whether disasters bring similar and large negative impacts throughout the heterogeneous sectors of an economy. The literature indicates that the economic response differs according to the magnitude of a disaster although such findings are inconclusive when other variables such as the scope, scale, type of disaster, the type of economy, etc., are taken into account. Natural disasters—such as a tsunami—may largely have a negative impact on an economy's growth rate, whereas in some instances such disasters may have a positive effect through the rebuilding of destroyed assets with superior and more advanced technology.

The literature on this field is mainly based on endogenous and neo-classical growth theories. After the seminal paper by Albala-Bertrand (1993), many researchers subsequently looked into the impact of disasters on long-term growth. Some predicted that the destruction of capital would drive countries temporarily away from a balanced growth path (Jovel, 1989; Krimgold, 1974; Noy, 2009). Others predicted that even higher growth rates would be experienced after a disaster event (Cavallo et al., 2013; Hallegatte & Dumas, 2009; Loayza et al., 2012; Tol & Leek, 1999). Hallegatte and Dumas (2009) investigated the positive impact of disasters that was achieved through the improvement of existing capital stock. However, the most recent research suggests that whether a natural disaster has a negative or positive effect on economic growth depends on different factors, and ultimately it has to be determined by empirical research (Cavallo et al., 2013; Klomp et al., 2009; Loayza et al., 2012).

Loayza et al. (2012) carried out one of the first studies that emphasized the need to investigate disaggregated economic sectors by going beyond the averaged national economic growth figures. Mohan et al. (2018) examined the different national accounting components of the Gross Domestic Product (GDP) of countries experiencing large natural disasters, especially, hurricane destruction. They concluded that the response of diverse components underlying the GDP is heterogeneous among different sectors. Thus, exploring the impact of disasters was likely to be more complex when it entailed going beyond aggregated sectors. These new findings in the literature on the effects of disasters on economic growth, which go beyond the aggregated disaster impact on aggregated economic growth, have yet to be corroborated but new studies are still rare.

The current study therefore, goes beyond aggregated economic sectors that include agricultural, industrial and services sectors using Sri Lankan provincial level data. Moreover, the study looks into the time specific disaster-economic growth nexus in order to understand the catching up process that follows the destruction wreaked by disasters. Hence, this study is a complex and comprehensive effort to add knowledge to current literature on the disaster-economic growth nexus. In doing so, the focus is on the literature on agriculture dependent small and developing economies that are highly vulnerable to different disasters.

The remainder of the paper is organized as follows. Section 2 presents the methodology and Sect. 3 presents the results followed by a discussion. Section 4 concludes the study with policy recommendations.

2 Data and Methods

The study employs Sri Lankan provincial administrative level data (Sri Lanka constitutes of 9 administrative provinces) in order to capture the impact of different disasters on different economic sectors while taking into account the heterogeneous environment of the country. Hence, data on both GDP and on different disasters is employed. Following the system of National Accounts (2008), GDP has been disaggregated under three main components of the economy—agriculture, industry and services. The data span is from 1997 to 2018. Depending on the analysis and the context, the time span and number of provinces used were adjusted. Inflation-adjusted constant GDP is used throughout the analysis.

The study employs the disaster index, particularly tsunami index in order to capture the impact of 2004 tsunami. Following Fomby et al. (2013) and Keerthiratne and Tol (2017), the population affected from tsunami was employed for the construction of the index. The level of severity is measured using populations affected in each province (i) and in particular, the change in severity over time (yearly) (t). This index is formed normalizing the total population of the previous year in each province. The data was collected from the *Disinventa*r database which is managed by the Disaster Management Center of Sri Lanka.

Difference-In-Difference method (DID)

To investigate the deeper effects of tsunamis, the DID methodology has been employed in a number of previous studies on disaster impacts (Matsuki & Managi, 2016; Rajapaksa et al., 2016). The econometric model employed is as follows:

$$y_{it} = \beta_0 + \beta_1 Damaged_i + \beta_2 After_t + \beta_3 Damaged_i \times After_t + \beta_4 Control_i + \varepsilon_{it} \quad (1)$$

where y_{it} is the log of GDP for different economic sector variables (agriculture, industry and services). $Damaged_i$ is a dummy equal to one if a province is situated in a devastated area, $After_t$ is a dummy equal to one if t is 2005 or 2006; $Control_i$ is selected as a control variable and ε_{it} is the error term.

Time series tests: vector auto regression analysis

To capture the time specific impact on disaster variables on the agriculture sector the panel vector auto regression framework is employed as it facilitates the exploration of external shocks on the economy. The reduced form of the panel vector auto regression model with exogenous shock, (P)VARX takes the form of the following equation:

$$y_t = \Psi_i + \Sigma_{j=1}^{p} \beta_i y_{t-j} \Sigma_{k=0}^{s} \pi_k x_{t-k} + \varepsilon_t \quad (2)$$

where y represents the vector of endogenous variables, namely GDP for agriculture, industry and services; x is the exogenous variable that forms the basis of the tsunami index t stands for time and ε stands for error term. When the panel structure of the data and the panel fixed effect methodology are taken into account, the equation can be written as:

$$y_{i,t} = \Psi_i + \Sigma_{j=1}^{p} \beta_i y_{i,t-j} \Sigma_{k=0}^{s} \pi_k x_{i,t-k} + \varepsilon_{i,t} \tag{3}$$

where i is the provincial index and Ψ_i captures the fixed effect for each country. This equation can be written in the following multiplier form:

$$y_{i,t} = \Omega(L)^{-1} \Phi(L) x_{i,t} + \Omega(L)^{-1} \sigma_{i,t} \tag{4}$$

where L stands for the lag operator and the average reaction of the tsunami shock is captured by $(L)^{-1}\Phi(L)$. The lag structure is an important aspect of this kind of analysis. Both AIC and BIC criteria are employed to select preferable lags. An important assumption of the PVARX technique is that the endogenous variables included in model (x) must be stationary. Hence, order of integration of the variables is an important part of the estimation. For that purpose, both the Levin, Lin and Chu (LLC) unit root test (which assumes that the individual time series in the panel is cross-sectional and independently distributed) and the Pesaran and Shin (CIPS) panel unit root test—which assumes cross sectional dependence as well as serially correlated errors—are employed. Both of these tests were suggested and used by previous studies on this same topic (e.g. Mohan et al., 2018).

3 Results and Discussion

Following the tsunami of 26 December 2004, the greatest impact was felt in the year 2005. The tsunami's impact on different economic sectors is compared over the years 2005–2007. As can be seen in Table 1, in 2005 there was around a 0.7% decline in growth in both the agricultural and industrial sectors. The impact on the services sector was also negative, but it was smaller. However, in 2006, only the agricultural sector showed a negative impact while both the industrial and services sectors grew significantly. This growth continued through the year 2007 although the impact on agriculture continued to be negative. Though these results are indicative, they help to confirm that the agriculture sector is the most highly impacted sector from disasters while the industry and services sectors have shown the capacity to grow after large scale disasters, as many previous studies have shown.

These results are in line with the previous analysis. Interactions with the year dummies for 2005 and 2006 are negative and significant for the agriculture sector while the interaction term for the year 2007 dummy is not significant but with a positive sign. The industry and services sectors show a negative impact only in the first year and thereafter it is positive.

In Table 2, the outcomes from the basic model are set out and include *damaged, after* and the key DID variable—Damaged**after* interaction. The DID variable is negative and significant for agriculture, confirming the results of the previous

Table 1 Impact of the 2004 Tsunami on different economic sectors 2005–2007

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Variables	Agri	Industry	Services	Agri	Industry	Services	Agri	Industry	Services
Tsunami_2005	−0.00731**	−0.00760**	−0.00148						
	(0.00257)	(0.00256)	(0.00172)						
Tsunami_2006				−0.0112*	0.0124*	0.00671**			
				(0.00455)	(0.00480)	(0.00218)			
Tsunami_2007							−0.00316	0.00460*	0.00295*
							(0.00203)	(0.00180)	(0.00122)
Log_density	0.118	−0.0247	−0.0405	0.141	−0.0233	−0.0344	−0.294	0.0857	0.0328
	(0.111)	(0.0686)	(0.0437)	(0.0988)	(0.0165)	(0.0228)	(0.330)	(0.0585)	(0.0607)
Constant	−0.483	0.427	0.478	−0.542	0.343**	0.411**	1.934	−0.300	0.00272
	(0.624)	(0.381)	(0.244)	(0.556)	(0.0887)	(0.133)	(1.838)	(0.321)	(0.341)
R-squared	0.116	0.135	0.059	0.290	0.395	0.583	0.238	0.301	0.447
Number of pcode	5	5	5	5	5	5	5	5	5

Robust standard errors in parentheses, Tsunami refers tsunami index, pcode refers to number of provinces affected by tsunami, $^{***}p < 0.01$, $^{**}p < 0.05$, $^{*}p < 0$

Table 2 DID analysis for the 2004 tsunami with "*damage*after*" interaction

	(1)	(2)	(3)
Variables	Agri	Industry	Services
Damaged	0.00140	0.365	0.113
	(0.239)	(0.417)	(0.321)
After	−0.299***	−0.559***	−0.537***
	(0.0594)	(0.107)	(0.0315)
Dam*after	−0.190**	0.515**	0.386
	(0.0936)	(0.249)	(0.274)
Log_density	0.222***	0.784***	0.722***
	(0.0841)	(0.149)	(0.116)
Constant	9.684***	6.690***	7.961***
	(0.475)	(1.022)	(0.781)
Observations	162	162	162
Number of pcode	9	9	9

Robust standard errors in parentheses, pcode refers to number of provinces, ***$p < 0.01$, **$p < 0.05$, *$p < 0.1$

analysis. However, for industry it is positive and significant while for services the sign is positive, but not significant. Table 3 reports the estimated coefficient when year dummies are employed instead of the "*after*" dummy. The interaction of the area dummy and the year dummy of 2005, 2006 and 2007 signify recovery from the tsunami, indicating the nature of the impact of major disasters on developing economies.

The impact on differently affected provinces is set out in Table 4. As described earlier, the tsunami impacted the coastal areas of Sri Lanka in the southern, western and eastern seaboard causing considerably more damage than in other areas. In

Table 3 DID analysis for the 2004 Tsunami with "*damage* year*" interaction

Dependent variable	Independent Variable	Coefficient	S.E
Log (Agri)	Damage*2005	−0.203***	(0.0832)
	Damage*2006	−0.257***	(0.0580)
	Damage*2007	0.0867	(0.153)
Log (Industry)	Damage*2005	−0472***	(0.164)
	Damage*2006	0.836***	(0.135)
	Damage*2007	0.659***	(0.180)
Log (Service)	Damage*2005	−0.367***	(0.107)
	Damage*2006	0.600	(0.112)
	Damage*2007	0.530	(0.136)

Robust standard errors in parentheses ***$p < 0.01$, **$p < 0.05$, *$p < 0.1$

Table 4 DID analysis for the 2004 Tsunami with "*Province*after*" interaction

Dependent variable	Independent variable	Coefficient	S.E
Agri	East*after	−0.313***	(0.0586)
Industry	East*after	0.0109	(0.093)
Services	East*after	−0.0871	(0.050)
Agri	South*after	−0.0566	(0.078)
Industry	South*after	0.274***	(0.012)
Services	South*after	−0.0598	(0.088)
Agri	West*after	−0.211***	(0.069)
Industry	West*after	0.356***	(0.104)
Services	West*after	0.673***	(0.147)

Robust standard errors in parentheses, ***$p < 0.01$, **$p < 0.05$, *$p < 0.1$

this analysis, provincial dummies were employed (south, east and west) instead of a year dummy. The agriculture sector in all three provinces shows a negative sign while in the eastern and western provinces, significant damage is indicated. For the southern province, the interaction did not show a significant impact. These negative impacts on the agriculture sector should be mainly attributed to damage to the fisheries sector, which contributes around 10% to the agricultural GDP and accounts for a considerably higher share in the Eastern and Western provinces of the country. Interestingly, dummy interactions for the industrial and services sectors in the Western province are highly significant and positive implying an increase in GDP for both these sectors of the Western province as a result of the tsunami. Being the capital province—which includes Sri Lanka's capital city—the Western province is the most industrialized as well as constituting the hub of the country's services sector. These results indicate the increase in demand for reconstruction and "building back better" infrastructure after disasters as well as considerable aid and grants being received for advancement of the industrial and services sectors. Moreover, the services sector generates more services after a catastrophic event and also helps to increase the GDP of the sector.

Time series PVARX analysis results

An important assumption of the PVARX technique is that the endogenous variables included in model (x) must be stationary. Hence, the order of integration of variables is an important part of the estimation. For that purpose, both the Levin, Lin and Chu (LLC) unit root test (which assumes that the individual time series in the panel is cross-sectional and independently distributed) and the Pesaran and Shin (CIPS) panel unit root test—which assumes cross sectional dependence as well as serially correlated errors—are employed.

Further, the LLC test assumes that the coefficient of the autoregressive term is homogeneous across all panels (i) and examines the null hypothesis of $H_0{:}\varphi = 0$, against the alternative H_1:$\varphi < 0H_1 : i < 0$. The results of LLC and CIPS are set out in Table 5.

Both tests show that all variables are not stationary at the same time when the levels are tested. However, after differencing all variables become stationary, indicating that these variables are integrated to the order of one, i.e., I (1). With the intention of making estimated coefficients comparable across all GDP components, the first difference of all variables is used for the analysis. BIC criteria are employed to select preferable lags.

Results of the dynamic responses of different economic sectors to the tsunami shocks are presented in Fig. 1. Considering the limitations of small datasets, the

Table 5 LLC and CIPS test results

Variables	LLC			CIPS test		
	Test-Stat	*p*-Value		Test stat	*p*-Value	
Ln (Agri)	3.741	0.000	I(0)	2.967	2.34	I(0)
Ln (Industry)	0.654	0.743	I(1)	1.643	2.34	I(1)
Ln (Services)	1.890	0.293	I(0)	1.745	2.34	I(I)
dln (Agri)	5.827	0.000	I(1)	4.734	2.34	I(1)
dln (Industry)	2.934	0.001	I(1)	4.371	2.34	I(1)
dln (Services)	13.395	0.000	I(1)	3.529	2.34	I(1)

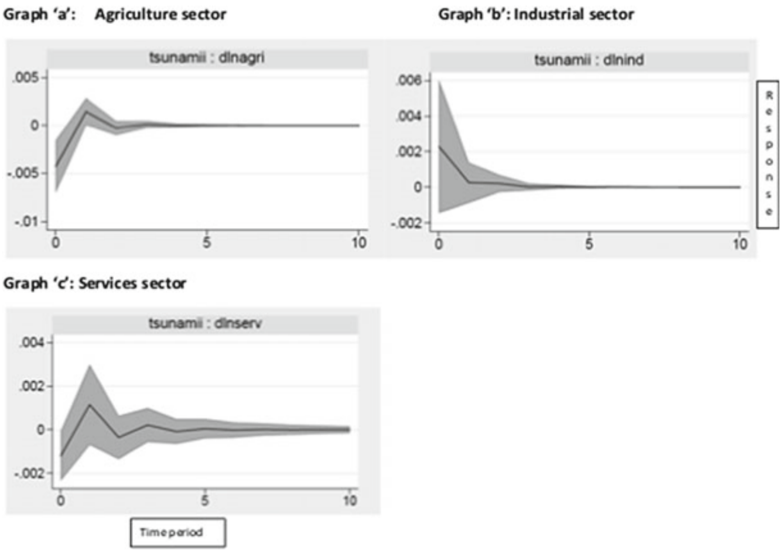

Fig. 1 Impulse responses of different economic sectors for tsunami shock. Mean responses of the different economic sectors' growth to the tsunami index (x axis represents the time period while the y axis represents the response in the graph)

whole dataset is employed, which includes data from 1997 to 2018. Hence, it is acknowledged that the strength of response by different sectors can have an averaging bias due to averaging the data that covers a longer period. Thus, the pattern of the graphs indicates the behavior of the growth of different economic sectors of a developing economy in relation to a sudden impulse in the form of a major natural disaster. This is in line with the findings of the previous literature (Fomby, 2013; Raddatz, 2009; Mohan et al., 2018).

As indicated by the dynamic multiplier effect presented in Graph 'a' in Fig. 1 the instantaneous effect of a tsunami shock was first significantly negative for the agriculture sector but subsequently it stabilized after about three years. These results are consistent with this study's previous analysis, including the DID analysis that indicated that the agriculture sector experienced two years of significant negative effects although in the long run, the effect became insignificant. As per Graph 'b' in Fig. 1, the instantaneous effect of the tsunami shock on the industrial sector was positive but not significant. However, the pattern itself gives an insight into the industrial growth after such a devastating event. The previous results as well as the past literature (Noy, 2009; Loayza et al., 2012) support this conclusion. A possible reason for this behavior is that, after a disaster, governments typically take action to immediately repair damaged infrastructure. As well, new machinery and technology are likely to be purchased by governments—which may be funded by foreign aid—and this can also improve this sector's growth. As shown in Graph 'c' the immediate impact on the services sector was negative and significant although it became positive over time with some fluctuations. With a very high magnitude disaster, the extensive destruction of human capital and infrastructure of the sector produces an immediate slowdown in that sector's growth. However, there is likely to be an overall improvement in the country's economy from the generation of increased services as well as infrastructure rehabilitation, which in turn produce a positive impact on the services sector.

4 Conclusions

Theoretical and empirical results in the literature on the impact of natural disasters on economic growth are rather ambiguous. This is mainly because the economy as a whole and its major sectors are too broad to indicate clearly the impacts of different disasters. Moreover, no uniform impact is indicated by studies of various economic sub-sectors. This study's major finding is that the agriculture sector suffers most from disasters while the impact on industry and the services sectors is positive when considering longer term impacts. The negative impact on the agriculture sector prevails over a longer period compared to the other two economic sectors while the negative impact on the overall growth is visible a year after the occurrence of the disaster. Both DID analysis and VARX analysis of the tsunami event also confirm that after an extreme catastrophic disaster, the agriculture sector is the most vulnerable as well as being the sector that suffers most over an extended period of time when compared to the other sectors.

Much of the literature on the impact of disasters on such matters as crop production and food security, also notes the presence of the same vulnerability in the entire agriculture sector (Auffhammer et al., 2012; Jawid & Khadjavi, 2019; Knox et al., 2012; Morton, 2007; Nguyen & Nguyen, 2020; Schroth et al., 2009). As Knox et al. (2012) point out, in Africa and South Asia the major grain sectors are projected to suffer mean yield losses of 8% by 2050 due to disaster events.

This study is subject to a number of limitations. The investigation is based on aggregated data in respect of different economic sectors. However, not all subsectors of the different economic sectors are equally vulnerable to disasters. The data set that covers a 20-year time span reveals a number of these limitations. As well, in terms of analysing the factors affecting the economic growth of the broader economic sectors, it is impossible to incorporate all of the relevant predictors to explain the outcome variables—as is noted in the literature (Neter et al., 1996). Further, it was not possible to use some of the variables utilized by many previous studies (e.g. Loayza et al., 2012; McDermott et al., 2015) as this study focused on the provinces within a single country.

In respect of policy implications, this study indicates that policy makers should pay more attention to implementing climate and disaster related adaptation practices for the agriculture sector. However, these practices should be tailor-made to suit specific agricultural sub categories, as common adaptation practices applied to different agricultural sub-sectors could well lead to more harm than benefits. While district level and provincial level programs to popularize planned adaptation practices are crucial, farmer level and plantation level awareness of climate change issues can be seen as necessary to increase the adoption rate of adaptation practices.

In relation to the other sectors, line ministries should be aware of the benefits that can be derived from disasters as a result of the high demand that occurs for various services in emergency situations. Therefore, policies should be formulated to enhance the efficiency and productivity of those sectors. It will help to deliver a higher level of service and greater output even under limited capacities. This should apply not only to ministries and departments involved in disaster management, but to all entities engaged in production processes and the provision of services. All these industrial/commercial units should incorporate effective disaster management policies in their mandates and should train their employees to deal with disaster situations in a more effective way. Further, the referred literature also emphasizes the importance of proper planning for the management of natural capital. In particular, pre- and post-disaster management policies should be designed and implemented not only to deal with large disasters but also to cope with the more frequent small-to-medium level disasters.

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Disaster Preparedness

Synoptic and Mesoscale Background of the Disastrous Heavy Rainfall in Sri Lanka Caused by a Low Pressure System

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Abstract Sri Lanka is having tropical and monsoonal climatology and southwest monsoon is the longest monsoon season (May to September) which brings about 30% of the total annual rainfall of the country. Average onset of southwest monsoon is 25th May (±5 days) over southern part of Sri Lanka. Low level disturbances associated with the Inter Tropical Convergence Zone (ITCZ) develop over or in the vicinity of Sri Lanka affect the weather of the country during pre-monsoon season. In mid May 2016, atmosphere around Sri Lanka was very unstable. Extremely heavy rainfall, exceeding more than 200 mm in a day, was received in many parts of the island leading to flood and landslide on 15th May 2016. It caused massive damages to human lives as well as the economy of Sri Lanka. Total financial damage was estimated at 250–280 billion rupees (US$1.7–2 billion) and caused nearly 200 casualties. This study is focused to analyse the synoptic situation during the said period. Synoptic observation, JRA 55 Reanalysis data are used to generate synoptic charts. Behavior of wind patterns at different levels of the atmosphere, change of atmospheric pressure were analysed. Satellite data also analysed and analysis clearly showed that this extreme rainfall was associated with a low pressure area developed in the Bay of Bengal closer to Sri Lankan eastern coast and it was initial stage of Cyclone "ROANU".

Keywords Monsoon · Synoptic · Low pressure area · Extreme rainfall

1 Introduction

Extreme rainfall events today pose a serious threat to many populated and urbanized areas worldwide. An accurate estimate of frequency and distribution of these events can significantly aid in policy planning and observation system design (Goswami & Ramesh, 2007). Extreme rainfall with flood and landslides is more frequent in

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the world today due to change in weather pattern and improper land use changes. Many parts of Sri Lanka are vulnerable to extreme events leading to flood and drought (Arunasalam et al., 2019). In Asia, floods are by far the most frequent and devastating natural disasters (Dushmanta, 2004). Compared to the decade ending in 1983, the number of disasters caused by natural hazards has increased by 22 times during the last decade mainly due to increased hydro-meteorological disasters. In terms of the frequency of disasters affecting the people and economy, flood is the highest[1] (56%) followed by drought (18%), high winds (10%) and landslides (16%) (Asia Pacific Alliance for Disaster Management Sri Lanka). Therefore, an understanding of the characteristics of extreme rainfall events is important, as these events cause extensive damages to the ecology, infrastructure, agriculture, economy, environment, human settlements, etc. (Coates, 1996).

Most recent heavy rainfall events in Sri Lanka during the month of May occurred in 2016, 2017 and 2018. In May 2016, tropical storm ROANU caused flooding and landslides in 22 out of 25 districts. According to the preliminary post-disaster needs assessment done by Global Facility for Disaster Risk Reduction (GFDRR), damages and losses exceeded $570 million.

Heavy rainfall over Sri Lanka on 15 May 2016

Sri Lanka (5°–10° N and 80°–83° E) is an island situated at the interface of two sea areas with the Bay of Bengal to the East and Arabian Sea to the west. Sri Lanka has 2 major monsoons, southwest and northeast associated with the southwesterly and northeasterly regional wind patterns respectively. Within these monsoons there are two inter-monsoon seasons when convective activities are dominant. The central part of the southern half of the island is mountainous with heights more than 2.5 km. The core regions of the central highlands contain complex topographical features such as peaks, hills, basins, and valleys. The rest of the island is basically flat except for several small hills in the lowlands. These topographical features strongly affect the spatial patterns of winds, seasonal rainfall, temperature, relative humidity and other climatic elements, particularly during the monsoon season.

Formation of Tropical depressions and storms in the Bay of Bengal usually occur in pre-monsoon and at the onset of southwest monsoon period (from latter part of April to June). The onset of southwest Monsoon normally occurs either with the gradual setting of winds of moderate strength, or with a burst by a formation of depression in the Southwest Bay of Bengal. On the other hand if such a system is formed in the Arabian Sea during the mid-May or first week of June the onset will be late or weak. However, this tropical depression is likely to produce greater impacts when it is formed close to Sri Lanka or having a projected path along or close to the Eastern coast of Sri Lanka. The areas that usually receive the heaviest rainfall are the South and West of the country, including the major cities of Galle, Mathara, Kalutara, Ratnapura, and Colombo.

[1] Impacts of Disasters in Sri Lanka 2016, Ministry of Disaster Mangement in Sri lanka and Asia Pacific Alliance for Disasters Sri Lanka.

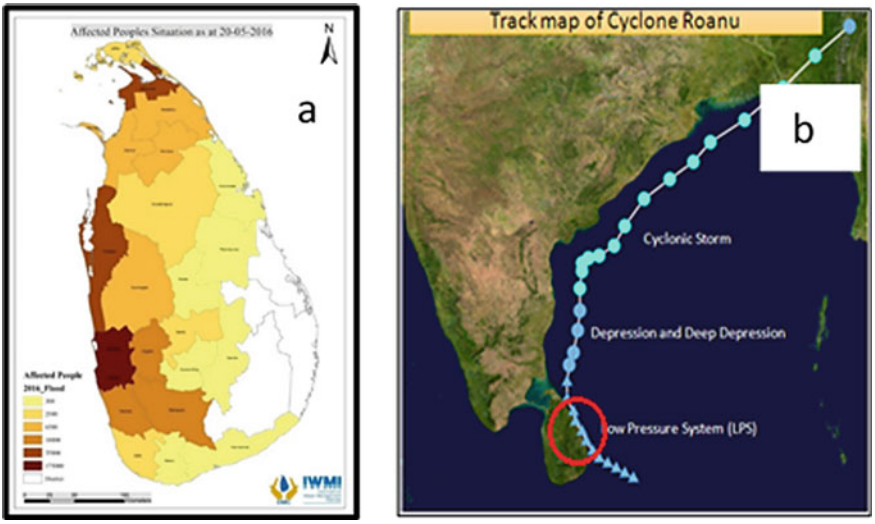

Fig. 1 **a** The affected number of people (*Source* IWMI) and **b** The track of the tropical cyclone ROANU (*Source*—Indian Meteorological Department) (during 14–16 red circle)

Onset of southwest monsoon of 2016 was induced by a low-pressure system which was at the initial stage of the tropical cyclone 'ROANU" in the Bay of Bengal (Track and the number of people affected due to heavy rain are shown in the Fig. 1). It has caused massive damage to human lives and the economy of Sri Lanka with flooding and landslides in the western Sri Lanka, during the third week of May 2016 although it did not make a landfall in Sri Lanka. Very heavy rainfall exceeding 200 mm (highest was 373.2 mm at Kilinochchi in the Northern part of Sri Lanka) within 24 h was received in the western and northern parts of Sri Lanka on 15 May 2016 (Fig. 2b). There were around 93 casualties and still 113 people were missing. In all, 619 houses were destroyed, and 4294 were partly damaged, affecting a total of 472,775 families (Fig. 1a) due to floods and land Slides. (Report on 2016 Sri Lanka flood, Disaster Management Center, Sri Lanka/International Water Management Institute).

Initially the "ROANU" cyclone was developed as a low level disturbance associated with the ITCZ on 10th of May, to the South of Sri Lanka and remained at the same intensity around Sri Lanka until 14 May 2016· It developed into a low-pressure area over southwest Bay of Bengal (BoB) to the Southeast of Sri Lanka on 14th May 2016. It moved northeastwards along the east coast of Sri Lanka while intensifying into a well-marked low pressure area in the morning of 15 May 2016. It further moved northwestwards and lying over Trincomalee coast of Sri Lanka and Southwest Bay of Bengal in the morning of 16 May 2016. Thereafter, moving north-northwestwards, it concentrated into a depression and lay centered over southwest Bay of Bengal off Tamil Nadu coast on 17th near 11.00 N and 81.0 E. It further moved, and intensified into a deep depression, on 18th. It further intensified into a cyclonic storm and continued to move northeastwards along the East coast of India

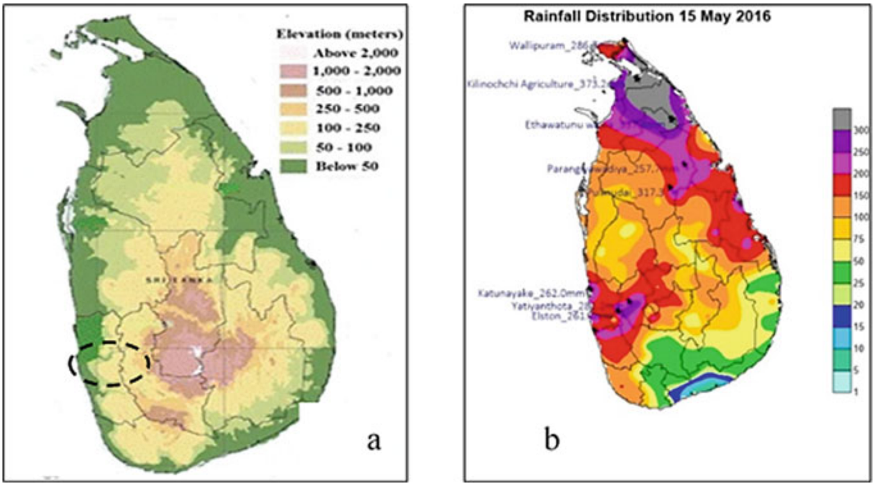

Fig. 2 **a** Topography and provincial boundaries of Sri Lanka (*Source*—Galgamuwa et al., 2018) and **b** Spatial daily rainfall distribution over Sri Lanka on 15th May 2016

during 19–20 May 2016. It crossed Bangladesh coast on 21st as a Cyclonic Storm. Cyclone ROANU followed a unique track (Fig. 1b), moving very close to Sri Lanka and East coast of India. It recurved northeastwards and crossed Bangladesh coast to the north of Chittagong (Fig. 1, source-Indian Meteorological Department).

Under the influence of the system rainy condition over the country started on early morning of the 15th and highest daily rainfall of 373.2 mm was observed in the Kilinochchi district, Northern province (Fig. 2b). Sabaragamuwa province which connected to the Kelani River (Fig. 2a-in black circle) basin in the western slopes of the central hills also received considerable amount of rainfall. Due to heavy rainfall in both lower and upper catchment of Kelani river basin, river flooding was experienced over downstream of the Kelani river basin, especially in the Colombo Metropolitan region and caused massive landslides along the western slopes of the central hilly areas in the Kegalle district of Sabaragamuwa province.

The objective of this study is to identify and document the possible synoptic and environmental characteristics of the heavy rainfall events on the 15th May 2016 over western and Northern parts of Sri Lanka.

2 Data and Methodology

- The largescale atmospheric pattern associated with the cyclone "ROANU" was reconstructed using JRA 55 and NCEP Reanalysis data. Spatial resolution of the data of JRA55 and NCEP was (2.5° × 2.5°) and (1° × 1°) respectively,

- Interactive Tool Analysis of Climate Systems (ITACS) software was used to study the data. (ITACS is developed by Japan Meteorological Agency (JMA).
- Atmospheric condition to develop the cyclone “ROANU” was carried out using the gridded data from NCEP and JRA55.
- Rainfall analysis during the heavy rainfall event was done using more than 250 daily observation data and Arc GIS was used to develop the spatial rainfall distribution map.
- GrADS (Grid Analysis & Display System) was used to analyse the horizontal and vertical profile of the atmosphere.
- Diagrams displaying amounts of precipitation were plotted by using ArcGIS software.

3 Results and Discussion

The data has been used to explore the possible causes and mechanisms behind the occurence of the heavy rainfall event over Sri Lanka on 15th May 2016 (during onset of southwest summer monsoon season). Figures 3, 4, 5, 6, 7, 8, 9 and 10 contain the

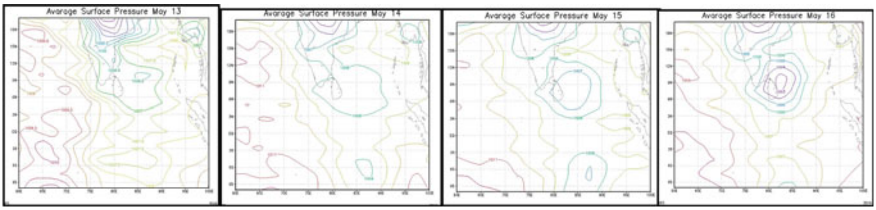

Fig. 3 Daily Average surface pressure distribution from 13 to 16 May 2016 (NCEP Reanalysis)

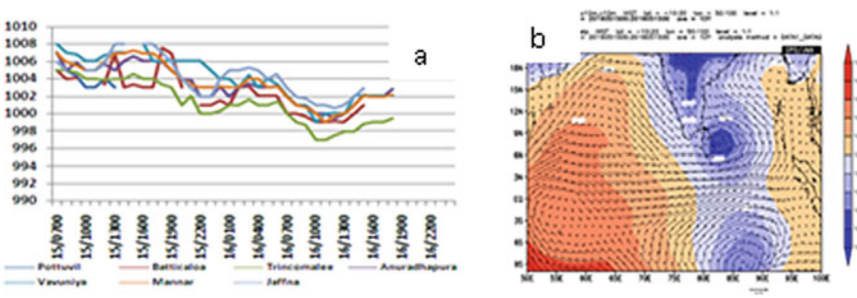

Fig. 4 **a** Hourly pressure distribution during 15/0700UTC to 16/2200UTC recorded at Department Meteorological stations in the Northern and Eastern parts of the country and **b** daily average mean sea level pressure (shaded) and surface wind (arrow) on 15th May 2016

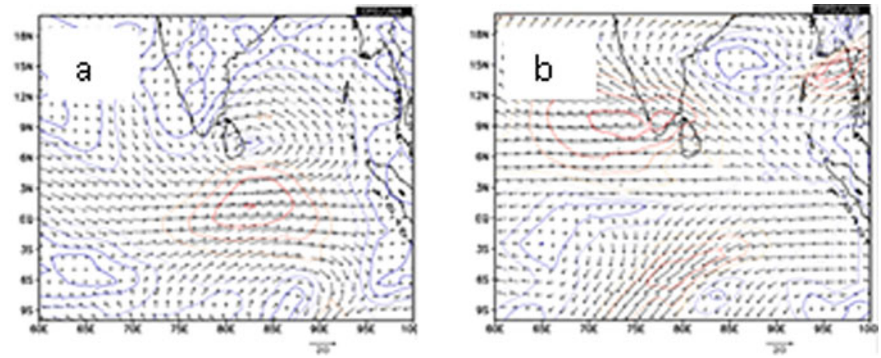

Fig. 5 The daily average **a** middle level wind distribution at 500 hPa and **b** upper level wind at 200 hPa on 15 May 2016

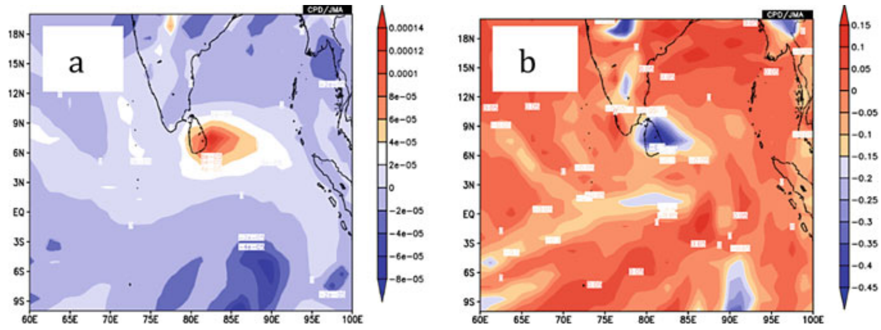

Fig. 6 Daily average low level relative vorticity (1/s) field **a** and pressure vertical velocity (Pa/s) **b** on 15 May 2016

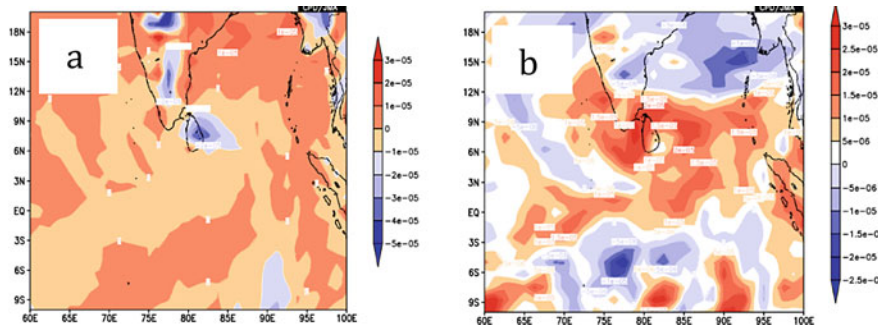

Fig. 7 The daily average low level-950 hpa **a** and Upper level-(200 hpa) divergence **b** on 15 May 2016

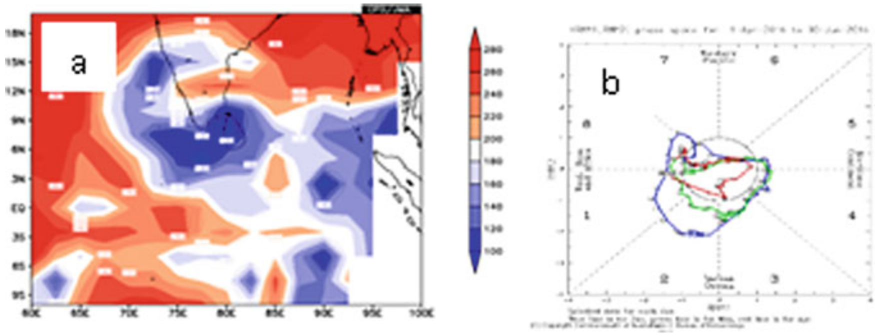

Fig. 8 **a** The outgoing longwave radiation (OLR) W/m^2 on 15 May 2016 and **b** Track of Madden Julian Oscillation (MJO) during April to June 2016

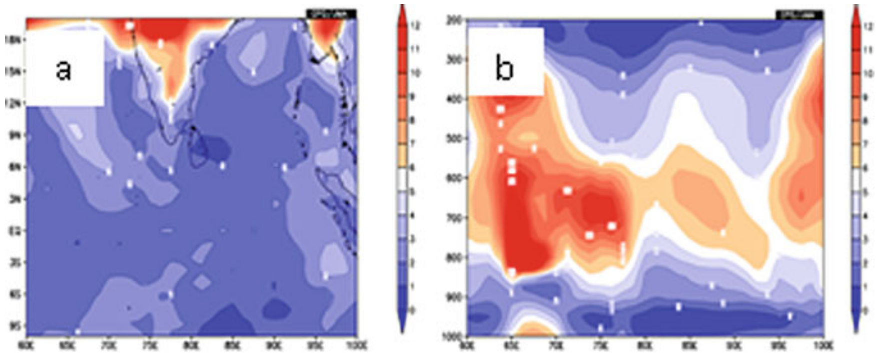

Fig. 9 **a** The dew point depression (T-Td)(K) analysis at 925 hPa level and **b** Vertical profile of dew point depression within latitudes 7°–10° N on 15 May 2016

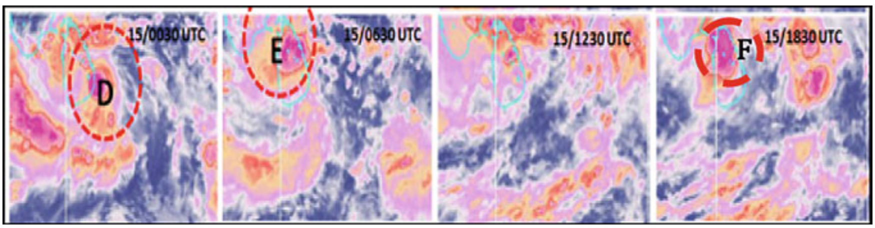

Fig. 10 The Chinese FY 2D satellite imageries on 15 May 2016

analyses of various synoptic maps of the flow variables on 15 May 2016. The results are described in the following section in details.

3.1 Synoptic Situation

(a) Mean sea level pressure and wind

The daily average mean sea level pressure (hPa) values during 13–16th May 2016 are shown in Fig. 4. It is found that a well-marked low pressure area was formed over Southwest Bay of Bengal (BoB) to the southeast of Sri Lanka on 15th May 2016.

The daily average mean sea level pressure (hPa) during 13–16th May 2016 is shown in Fig. 3. It is found that a well-marked low pressure area formed over Southwest Bay of Bengal (BoB) to the southeast of Sri Lanka on 15th May 2016.

Figure 4a shows the hourly pressure distribution at Department of Meteorology meteorological stations in Eastern and Northern parts of the country from 0700 h on 15th to 2200 h on 16th May 2016. Observed pressures at stations along the east coast of the country were lower than that of inland stations. The minimum pressure was recorded at Trincomalee on 16th Morning, suggesting that the system was moving along the east coast of the country.

Figure 4b shows the daily average mean sea level pressure and surface wind pattern on 15 May 2016. The isobars which are indicted by colours over the Southwest Bay of Bengal have east west run while over South East Arabian sea has almost west east run which enhanced the moisture feeding into country. It is found from the surface wind field that the westerly to northwesterly low level flow are moving towards the western coastal region and Northeasterly flow towards the Northern part of Sri Lanka where heavy rainfall was observed. This low level flow from the large area of Bay of Bengal and the Arabian Sea moves towards the country and converges over a narrow belt of the western and Northern part of the country where heavy rainfall was reported.

(b) Middle level (500 hPa) and upper level (200 hpa) wind

The daily average middle level at 500 hPa and upper level wind at 200 hPa wind distribution on 15 May 2016 are shown in Fig. 5a, b. It is found that a cyclonic circulation, a low pressure area, observed in low level wind (Fig. 4b) is continuing up to the mid-level (500 hPa) of the troposphere. The out flow from a high pressure cell in central bay of Bengal is observed in 200 hpa level (Fig. 5b) with diverge pattern of wind over the region of Sri Lanka.

(c) Low level relative vorticity (1/s) and pressure vertical velocity (Pa/s)

Daily average low level relative vorticity field and pressure vertical velocity on 15 May 2016 are shown in Fig. 6a, b respectively. Both relative vorticity field as well as pressure vertical velocity fields show a very favorable condition for vertical development of clouds over the country and the vicinity.

(d) Low level convergence and upper level divergence

The daily average low level and upper level divergence on 15 May 2016 are given in Fig. 7a, b respectively. It is found that a distinct area of low-level convergence (negative divergence) extends from Bay of Bengal to Eastern part of the country with a maximum over the Eastern part of Sri Lanka (Fig. 7a). A well-defined area of the upper level divergence is evident in the divergence field (Fig. 7b) which is associated with the divergent flow of the upper level wind (Fig. 5b).

(e) Outgoing Longwave Radiation (OLR) and MJO

The Outgoing Longwave Radiation (OLR/W/m^2) on 15 May 2016 is shown in the Fig. 8a. It was found that the region of Sri Lanka is covered by low OLR of the order around 100 W/m^2. It is evident that the dense clouds are characterized over the Northern and Western parts of Sri Lanka. Figure 9b shows the track and amplitude of Madden–Julian Oscillation (MJO) index, which is a eastward propagating intra-seasonal oscillation with a low frequency on 30–60 day scale, during April to June 2016. It was found that the MJO is in middle of the phase 2 and 3 with amplitude of more than 1 during 7–18 May 2016 with maximum on 15 May 2016. Accordingly, MJO also contributed to enhance the convective activity over the Bay of Bengal on 15 May 2016.

(f) Horizontal and vertical profile of dew point depression (T-Td) and wind

Dew point depression (T-Td) is a useful indicator of how moist the air is. Figure 9a contains the analyzed dew point depression field at 925 hpa level and it indicates that heavy incursion of moisture into the country. A leading tongue of high moisture, about 90–100%, extending from the Southwest Bay of Bengal into northern part and from Arabian sea into western part of Sri Lanka is an exceptional feature of this map (Fig. 9b). A narrow zone of high moisture content, like a moisture river is seen over and in the vicinity of Sri Lanka within 1000–900 hpa levels (b). In contrast, low amount of moisture in the middle level (700–500 hPa) of the troposphere is evident.

The FY 2D satellite imageries are presented in Fig. 10. Deep convective clouds are observed over Northern (E), Western and Northwestern parts (F) of Sri Lanka and the vicinity, which are supported by the outgoing longwave radiation fields (Fig. 9a).

4 Conclusions

Based on this study, the following conclusions can be drawn.

A cyclonic circulation persisted at the mean sea level just to the East of Sri Lanka and adjoining Southwest Bay of Bengal. The low level wind field indicates that there were Easterly to northeasterly flow from the Bay of Bengal towards the northern part of Sri Lanka and Westerly to northwesterly flow from Arabian sea towards the Western part of Sri Lanka, which converged over the North and West region of Sri Lanka. The low level easterly flow and westerly flow helped to transport a high amount of moisture from the Bay of Bengal towards the Northern and from Arabian Sea towards the Western regions of Sri Lanka and vicinities respectively. Orographic effect also triggered to enhance the rainfall over western slopes of the central hills.

The strong low level convergence helped to carry moisture up to 700 hPa level and accordingly high relative humidity extended up to this level. However mid-level drier condition was another triggering factor for the enhanced rain. The high relative vorticity, low level convergence, upper level divergence, favorable pressure vertical velocity over Sri Lanka preceded the development of heavy rainfall.

There was low OLR over North and western part of the country and presence of MJO in phase 2/3 with higher amplitude was favorable for enhancement of activity in the Bay of Bengal.

Further study is required to understand more about such cases. High resolution data are needed to identify localized effects.

Acknowledgements The JRA-55 reanalysis dataset was provided by the JMA and is available at https://jra.kishou.go.jp/JRA-55/index_en.html. Preliminary analysis in the present study used the ITACS system developed by the JMA.

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Identification of Extreme Rainfall Events for the Period 1970–2019 in Sri Lanka Using Percentile-Based Analysis and Its Projections for 2100 for the Emission Scenarios of RCP 4.5 and 8.5

H. A. S. U. Hapuarachchi and Sarath Premalal

Abstract The hydrological hazards associated with extreme weather events have increased globally over the past few decades leading to floods, landslides, drought, heat waves etc. Major reason for such hazards is an increase in the amplitude and frequency of weather extremes. Sri Lanka, ranked second among countries most affected by extreme weather events in 2017 is expected to see a 1.2% annual GDP loss by 2050 due to climate change. Identification of trends in extreme climate events and projecting them into the future will be important to find adaptation strategies in order to mitigate the disasters associated with extreme weather. Therefore, this study is focused to identify the change in extreme rainfall events during last fifty years by comparison of number of heavy and very heavy rainfall events for the period 1970–1979, 1980–1989, 990–1999, 2000–2009 and 2010–2019. Daily rainfall data for 16 rainfall stations in the period 1970–2019 is used and percentile based extreme rainfall events is analyzed. The results show an increasing trend of extreme rainfall events in Sri Lanka at some places during the past two decades, but not at a significant level. Analysis was further extended to identify future extreme events, using the NEX-NASA CMIP5 daily rainfall data for the moderate emission scenario (RCP 4.5) and high emission scenario (RCP 8.5) for the three (3) climatic zones in Sri Lanka and for the four monsoon seasons. Number of extreme events above the 90th and 95th percentiles for the period 2005–2100 was considered for the analysis. Base period used was 1975–2005. Results show a significant increasing trend for heavy and very heavy rainfall events in the three climatic zones for both emission scenarios. However, the increasing trend is not much significant for some monsoon seasons in Sri Lanka.

Keywords Extreme rainfall · Percentile based · Emission scenarios · RCP

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1 Introduction

Over the last few decades, weather and climate extremes have become a major focus of researchers, the media and general public due to their damaging effects on human society and infrastructure (Sheikh et al., 2015). Extreme rainfall events today pose a serious threat to many populated and urbanized areas worldwide; an accurate estimate of frequency and distribution of these events can significantly aid policy planning and observation system design (Goswami & Ramesh, 2007). There is more evidence that increase of climate extremes with the global warming is mainly due to anthropogenic emission of greenhouse gases. IPCC (2014) pointed out that warming of the climate system is unequivocal, and that many of the observed changes are unprecedented over decades to millennia. The IPCC AR4 concluded that the possibility of increasing number of heavy precipitation events (e.g., 95th percentile) during the second half of the twentieth century in many land regions, even with the reduction in total precipitation amount. With these changes, flood and drought events are more frequent in the world during recent past. Analysis of historical climate data clearly shows a change in climate patterns worldwide. Changing of climate is now impacting many sectors in the world as water, energy, food security etc.

Globally, many researches have been conducted to identify climate extremes, because they are generally associated with climate related disasters. Floods, droughts, heat waves and strong winds are the most common disasters related to climate. Flood event of 2016 was one of the worst flood events in Sri Lanka ever. Extremely heavy rainfall with a maximum of 373.2 mm at Kilinochchi in Northern part of Sri Lanka was received. Except for the southeastern part of Sri Lanka, most places received heavy rainfall leading to flooding and landslides, impacting human and property loss. Prolonged drought extended until early 2018 in the dry and intermediate zones after the 2016 flood led to a severe disaster situation. Extreme rainfall followed by flood and landslide in 2017 and 2018 were the other two extreme rainfall in Sri Lanka. Post Disaster Needs Assessment report pointed out the loss and damage in 2016 and 2017 flood to be at 724 and 468 million US $ respectively. These flood and drought situations had a high impact on food security and water sector in Sri Lanka. Therefore, it is important to identify the trends of rainfall extremes and their future projection for planning and development in a country. Precipitation related extremes may increase in frequency and intensity over many areas of the globe (Sun et al., 2007; Allan & Soden, 2008), with substantial consequences for a variety of socio-economic systems (e.g. Diffenbaugh et al., 2005; Easterling et al., 2000).

In the backdrop of these observed extreme climate and disaster situations, many climate scientists in the world focused their research to find the trend and behavior of extreme climatic indices. Alexender et al. (2006), conducted a study to identify climate extremes related to temperature and precipitation worldwide using global temperature data from 2223 stations and precipitation data from 5948 stations, using RClimdex software developed by WMO/CCI/CLIVAR Expert Team (ET) in climate change and Monitoring Indices (ETCCDMI). The study focused on analysing decadal based extremes and the results showed a general increase in the precipitation indices, however compared with temperature changes, Alexander et al. (2006) found less spatially coherent pattern of change and a lower level of statistical significance.

Later it was duplicated in many regions using data from more stations to develop high-resolution maps, focusing on sector vulnerability based on climate extremes. Sheikh et al. (2015) carried out a research focused to identify climate extremes to the Asian region using daily time series data for 210 (265) temperature (precipitation) stations. Total extreme rainfall (95th and 99th) show mixed changes throughout South Asia, with no widespread spatial consistency. Both indices show weak, non-significant increases averaged over the whole of South Asia.

Similar studies conducted by New et al. (2006) for southern and West Africa, Cheong et al. (2018) south-east Asia and their results show, statistically significant trend for temperature related extremes whereas most of the precipitation related extremes do not show statistically significant trends, specially for percentile based extremes. However, studies conducted for Bamako and Ségou in Mali, by Toure Halimatou et al. (2017), from 1961 to 2014 showed a positive slope and significant decrease with a rate of 0.009, at 99th percentile.

There is no doubt about the significant increase of temperature as, most research clearly pointed out the significantly increasing trend of temperature related extremes. According to Clausius-Clapeyron law, there is a chance to hold more water vapor in the atmosphere with warmer atmosphere. Therefore, global warming may cause an increase of the atmospheric water vapor content and an intensification of the global hydrological cycle (O'Gorman & Schneider, 2009) and there is a direct influence for change precipitation. Increased heating leads to greater evaporation. However, the water holding capacity of air increases by about 7% per 1 °C warming, which leads to increased water vapor in the atmosphere, producing more intense precipitation events (Trenberth, 2011).

Precipitation related extremes are in frequent even there is a not visible increasing trend for long term time series. Therefore, it is difficult to show the statistically significant trend with the linear trend of extreme events. Punyawardane and Premalal (2013) and Abeysekara et al. (2016) carried out studies to find the trend of extreme rainfall in Sri Lanka by categorizing total number of extreme events in a five year (pentad) period. Results show a slight increasing trend at some locations, even though some stations clearly showed a higher number of extreme rainfall events in recent the 1 to 2 pentads.

Jayawardane et al. (2018), recently, conducted a similar analysis using data from 18 meteorological observation stations in Sri Lanka. Results indicated an increasing trend of percentile based extremes at few stations at 5% level, while many stations showed threshold based (above 10, 20, 30 mm etc.) extreme indices.

Most of the analyses do not indicate significant increase of precipitation related extremes, even with the higher water vapor holding capacity due to the global warming. The only conclusion that could be drawn is the erratic rainfall causing both flood and drought in quick succession (Abeysekara et al., 2016; Nissasnka et al., 2011; Punyawardane & Premalal, 2013).

The objectives of the present study are to identify the impact of climate change on precipitation extremes in the decadal periods 1990–1999, 2000–2009 and 2010–2019 at 16 stations and its future projection for 3 climatic zones in Sri Lanka. Analysis is focused to find the possible trends in three climatic zones, wet, intermediate and dry.

It is necessary to identify the behavior of precipitation extremes in the future, for the benefit of planning and development activities. Therefore, analysis is extended to find the future trends of extremes using NEX-NASA CMIP5 future projection data for moderate emission scenario (RCP 4.5) and High emission scenario (RCP 8.5) in decadal periods until 2100. Historical hindcast data for the period 1975–2005 was used as a base period to find the percentile values. Finally, analysis is focused to four monsoon seasons as shown below.

First Inter-Monsoon (FIM)—March to April, South West Monsoon (SWM)—May to September, Second Inter-Monsoon (SIM)—October to November and North East Monsoon (NEM)—December to February.

2 Data and Methodology

Daily precipitation data at 16 synoptic stations (less the number of missing data out of 22 synoptic stations in Sri Lanka) for the 30 year period representing three climatic zones, wet zone (annual total Rainfall > 2500 mm), intermediate zone (annual total rainfall between 1750 and 2500 mm) and dry zone (annual average rainfall < 1750 mm) since 1990 were used for the analysis. Selected stations and the three climatic zones are shown in Fig. 1.

Analysis was focused to find the number of rainy days above 90th percentile (Heavy Rainfall) and 95th percentile (Very Heavy Rainfall) for the five decades 1970–1979, 1980–1989, 1990–1999, 2000–2009 and 2010–2019 with respect to the percentile values calculated for the period 1961–1990. 90th and 95th percentile values were calculated using daily observation data for each station for the period 1961–1990 as the base period for climatological analysis, defined by the World Meteorological Organization (WMO). Number of days, with rainfalls above the 90th and 95th percentiles per year were categorized into decadal based for the periods 1970–1979, 1980–1989, 1990–1999, 2000–2009 and 2010–2019.

Future projections of extreme rainfall events have been calculated using available future projection data at National Aeronautics Space Administration (NASA) Earth Exchange Global Daily Downscaled Projections (NEX-GDDP) data set under Coupled Model Inter-comparison Project Phase 5 (CMIP5) and two of the four greenhouse gas emission scenarios known as Representative Concentration Pathways (RCP), historical and future climate precipitation projection, at high spatial (25 km) and temporal (daily) resolutions. The study was performed over three climatic zone in Sri Lanka for the historical period 1975–2005 and compared against gridded observations on daily scales. Future climate change was assessed over the future time slices, 2020–2029, 2030–2039, 2040–2049, 2050–2059, 2060–2069, 2070–2079, 2080–2089 and 2090–2099, under two Representative Concentration Pathways (RCP) scenarios 4.5 (moderate emission) and 8.5 (high emission) with respect to 1975–2005. Following 6 models were used for the analysis.

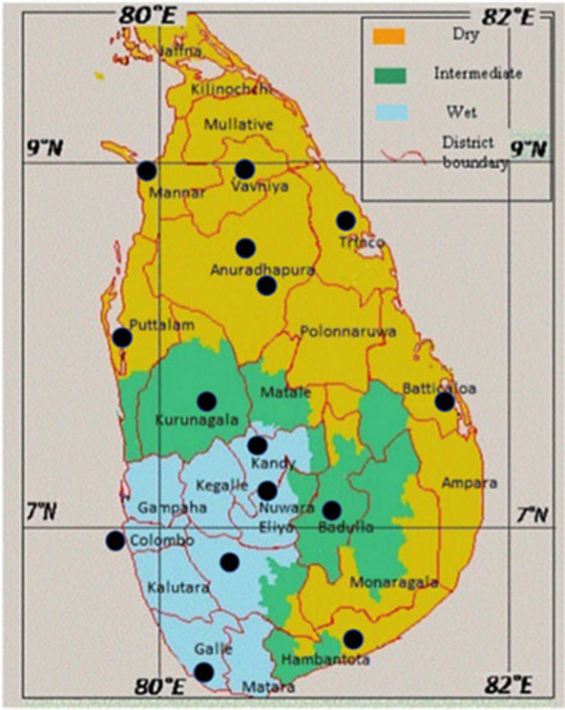

Fig. 1 Locations of 16 rainfall stations in Sri Lanka as used in this study

CanESM2	The Second Generation Coupled Global Climate Model Canadian Centre for Climate Modelling and Analysis
CNRM-CM5	National Centre for Meteorological Research/Meteo-France
CSIRO-MK3-6-0	Commonwealth Scientific and Industrial Research Organization (CSIRO) and the Queensland Climate Change Centre of Excellence (QCCCE)
GFDL-CM3	Geophysical Fluid Dynamic Laboratory NOAA, USA Coupled Climate Model
MRI-CGCM3	Global Climate Model of the Meteorological Research Institute, Japan (1.132 * 1.125)
NCAR-CCSM4	National Center for Atmospheric Research, USA Coupled Climate Model (0.942 * 1.25)

Base period was considered as 1975–2005 of hindcast data available at each model. 90th and 95th Percentile values were calculated for the period 1975–2005 and number of events above these two values for the six models was found. Median value for the 6 outputs from 6 model were considered for the visualization. Results are represented in graphical format with the regression equation, regression coefficient (R^2) and p value to identify the statistical significance.

3 Results and Discussion

Behavior of Heavy and Very Heavy Rainfall extremes 1970 -2019 in decadal base (observation data)

Figure 2a, b show the behavior of heavy rainfall events, and very heavy rainfall events respectively at selected locations in the dry, intermediate and wet zones.

Generally, the results indicated a higher number of extreme events during last two decades (2000–2009 and 2010–2019) at many places in the three respective zones. Most of the stations at dry zone and intermediate zone indicated a clear increasing trend (R^2 is high, but p value cannot be calculated due to low number of data points), but the trend is not significant in the wet zone.

However, most important part is to identify the extremes in future to make use of the results for development and planning purposes. Therefore, the study was extended to identify climate extremes for the period 2020–2100.

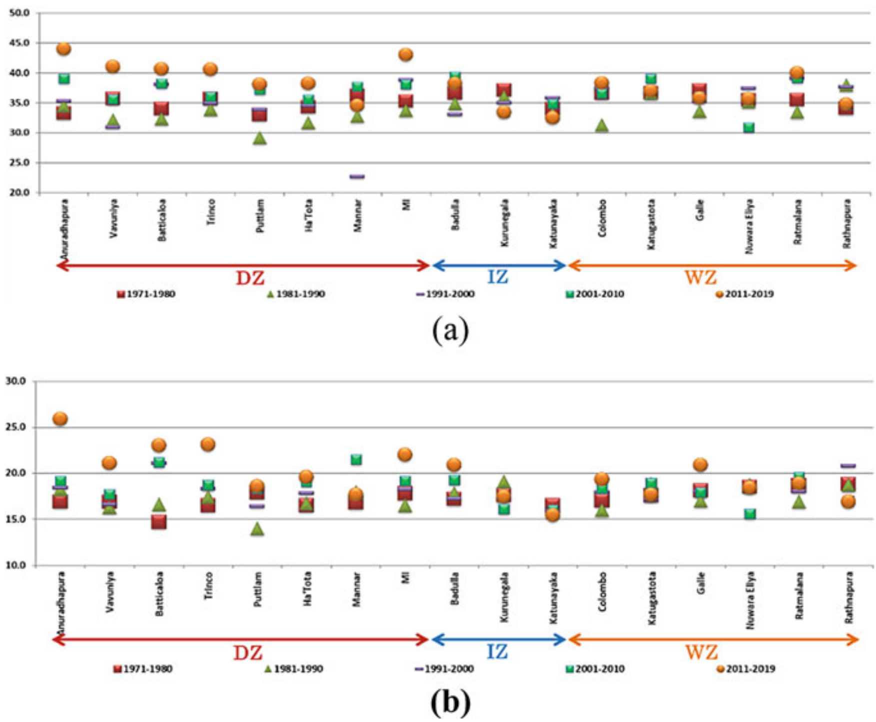

Fig. 2 **a** Heavy rainfall events **b** Very Heavy Rainfall events (Note: DZ—Dry Zone, IZ—Intermediate Zone, WZ—Wet Zone)

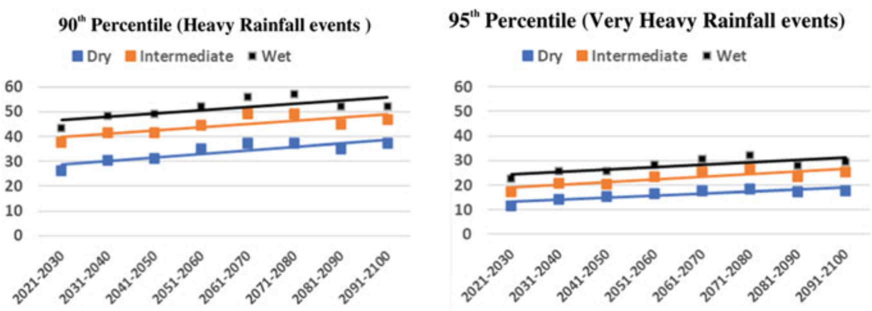

Fig. 3 Decadal behavior of heavy and very heavy rainfall events at 3 Climatic zones for moderate emission scenario (RCP 4.5)

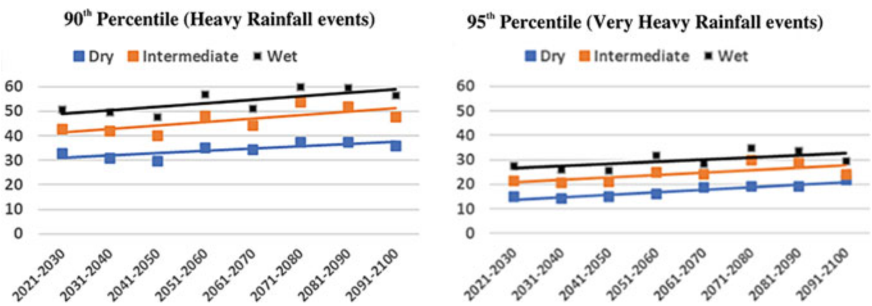

Fig. 4 Decadal behavior of heavy and very heavy rainfall events at 3 Climatic zones for high emission scenario (RCP 8.5)

Analysis of Extremes for the period 2020–2100

Figures 3 and 4 show the average number of heavy and very heavy rainfall events per year for the 8 future decades 2020–2029, 2030–2039, 2040–2049, 2050–2059, 2060–2069, 2070–2079, 2080–2089 and 2090–2099 at three climatic zones in Sri Lanka for both the emission scenarios used. Generally, analysis indicated an increasing trend at all three zones for both emission scenarios until 2100. Significant increasing trend is indicated for the moderate emission scenarios, but trends are not much significant for the high emission scenario, even when there is an increasing trend.

Relevant regression equations, Regression coefficients (R^2) and *p* values (significant test) for each time series for moderate scenario (4.5) and high emission scenario (8.5) are shown in Tables 1 and 2.

Analysis for 4 climatic seasons in Dry, Intermediate and Wet Zone (RCP 4.5)

Tables 3, 4 and 5 show the behavior of extremes for 4 monsoon periods (FIM, SWM, SIM, NEM) in Sri Lanka at 3 zones (DZ, IZ, WZ) for PCP 4.5. Regression equation, regression coefficient and *p* values (at 5% level), have been calculated to find the statistical significance.

Table 1 Regression equations, R^2 and *p* values (RCP 4.5)

4.5	Heavy	R^2	*P*	Very Heavy	R^2	*P*
DZ	Y = 1.44x + 27.2	0.750	0.005	Y = 12.4x + 0.8	0.790	0.003
IZ	Y = 1.29x + 38.6	0.628	0.019	Y = 1.07x + 18.0	0.732	0.007
WZ	Y = 1.30x + 45.4	0.532	0.040	Y = 0.99x + 23.4	0.617	0.021

Table 2 Regression equations, R^2 and *p* values (RCP 8.5)

8.5	Heavy	R^2	*P*	Very Heavy	R^2	*P*
DZ	Y = 0.93x + 30.0	0.597	0.025	Y = 1.02x + 12.8	0.899	0.000
IZ	Y = 1.43x + 39.8	0.526	0.042	Y = 0.97x + 20.1	0.490	0.053
WZ	Y = 1.42x + 47.5	0.545	0.036	Y = 0.90x + 25.6	0.470	0.089

Table 3 Regression equations, R^2 and *p* values (dry zone)

4.5	Heavy	R^2	*P*	Very Heavy	R^2	*P*
FIM	Y = 1.26x + 20.6	0.275	0.182	Y = 1.03x + 8.30	0.596	0.025
SWM	*Y = 5.12x + 65.7*	*0.744*	*0.006*	*Y = 2.54x + 27.3*	*0.663*	*0.014*
SIM	Y = 3.05x + 12.6	0.332	0.135	Y = 1.20x + 62.0	0.130	0.381
NEM	*Y = 4.96x + 59.5*	*0.603*	*0.023*	*Y = 3.63x + 26.4*	*0.668*	*0.013*

Note significant values are italicized in the table

Table 4 Regression equations, R^2 and *p* values (intermediate zone)

4.5	Heavy	R^2	*P*	Very Heavy	R^2	*P*
FIM	Y = 1.73x + 35.5	0.240	0.218	Y = 1.06x + 21.5	0.211	0.252
SWM	*Y = 4.76x + 134*	*0.553*	*0.034*	*Y = 2.99x + 52.4*	*0.338*	*0.130*
SIM	Y = 1.72x + 154	0.086	0.480	Y = 2.68x + 71.4	0.700	0.010
NEM	*Y = 4.70x + 61.8*	*0.568*	*0.031*	*Y = 3.96x + 34.6*	*0.741*	*0.006*

Note significant values are italicized in the table

Table 5 Regression equations, R^2 and *p* values (wet zone)

4.5	Heavy	R^2	*P*	Very Heavy	R^2	*P*
FIM	Y = 1.20x + 46.9	0.106	0.430	Y = 1.10x + 24.6	0.209	0.255
SWM	Y = 4.19x + 189	0.317	0.146	Y = 3.64x + 98.5	0.295	0.164
SIM	Y = 1.53x + 174	0.065	0.544	Y = 2.11x + 91.8	0.289	0.169
NEM	*Y = 6.08x + 44.1*	*0.646*	*0.016*	*Y = 3.06x + 18.9*	*0.592*	*0.026*

Note significant values are italicized in the table

All four-monsoon seasons indicated increasing trends at all zones. When comparing the slopes of the graphs, two major monsoons (Southwest and North-east) show higher increasing trends. It can be seen that number of heavy rainfall events are increasing significantly during Southwest monsoon in the dry zone, while it is significantly increasing during Northeast monsoon periods in the wet zone and intermediate zones (higher R^2 and lower p values). First inter-monsoon period does not show higher increasing trend.

Behavior of Heavy and Very Heavy rainy events for Moderate Scenario (RCP 4.5)—Three Zones (Dry, Intermediate and Wet)

Analysis for 4 climatic seasons in Dry, Intermediate and Wet Zone (RCP 8.5)

Tables 6, 7 and 8 show the behavior of extremes for 4 monsoon periods (FIM, SWM, SIM, NEM) in Sri Lanka at 3 zones (DZ, IZ, WZ) for PCP 8.5. Regression equation, regression coefficient and p values (at 5% level), have been calculated to find the statistical significance.

Table 6 Regression equations, R^2 and p values (dry zone)

8.5	Heavy	R^2	*P*	Very Heavy	R^2	*P*
FIM	Y = -,452x + 27.3	0.035	0.659	Y = 0.030x + 12.6	0.00	0.964
SWM	*Y = 6.00x + 62.1*	*0.870*	*0.001*	*Y = 5.04x + 19.4*	*0.852*	*0.001*
SIM	Y = 2.94x + 135	0.270	0.184	*Y = 3.30x + 61.3*	*0.675*	*0.012*
NEM	Y = 0.7 × 9 + 75	0.087	0.479	Y = 1.86x + 34.7	0.351	0.122

Note significant values are italicized in the table

Table 7 Regression equations, R^2 and p values (intermediate zone)

8.5	Heavy	R^2	*P*	Very Heavy	R^2	*P*
FIM	Y = –0.61x + 45.9	0.083	0.489	Y = -0.62x + 26.0	0.254	0.202
SWM	*Y = 7.20x + 133*	*0.415*	*0.084*	Y = 4.74x + 64.2	0.356	0.118
SIM	Y = 3.36 + 161	0.240	0.218	Y = 3.43x + 80.4	0.267	0.190
NEM	*Y = 4.35x + 57.9*	*0.585*	*0.027*	Y = 2.16x + 30.0	0.380	0.104

Note significant values are italicized in the table

Table 8 Regression equations, R^2 and p values (wet zone)

8.5	Heavy	R^2	*P*	Very Heavy	R^2	*P*
FIM	Y = −1.94x + 57.0	0.706	0.009	Y = −2.46x + 37.1	0.685	0.011
SWM	*Y = 8.01x + 188*	*0.370*	*0.110*	Y = 4.14x + 105	0.183	0.291
SIM	Y = 4.82x + 174	0.436	0.075	Y = 4.80x + 92.7	0.567	0.031
NEM	*Y = 3.82x + 56.4*	*0.412*	*0.086*	Y = 2.57x + 21.0	0.500	0.050

Note significant values are italicized in the table

All four-monsoon season indicated increasing trends at all zones except for the first inter-monsoon. A comparison of the slopes of the graphs shows a similar trend for all monsoon seasons except FIM. Results are almost similar to RCP 4.5, but heavy and very heavy rainfall events are significantly increased during SIM at the wet zone. It indicates a severe thunderstorm with the higher heating situation with more GHG emissions (RCP 8.5).

Behavior of Heavy and Very Heavy rainy events for Moderate Scenario (RCP 8.5)—Three Zones (Dry, Intermediate and Wet)

4 Conclusion

In Sri Lanka contribution for the total rainfall during FIM is nearly 14% and the FIM period expands to nearly 45 days starting from mid-March. Onset date of first inter-monsoon indicated the possibility of its shift towards April (data analyzed, but not published). With this situation it cannot be expected more extremes during FIM. During NEM, precipitation in wet and intermediate zone dominates with the evening thunderstorms and similarly dry zone dominates evening thunderstorms during SWM (Leeward side of Central mountains). This will be the reason for increasing heavy rainfall events in the dry zone during the SWM and wet zone in the NEM season. Many scientists pointed out that severity of cyclone can be increased with the global warming. If so dry zone during northeast monsoon will receive heavy rain with the formation of cyclones in the Bay of Bengal, as the possibility of developing cyclones in the south Bay of Bengal is more favorable during November and December. Development of low pressure areas/depressions/cyclones (Temporarily strengthening the southwest wind flow) in the Bay of Bengal it also a reason for increasing heavy rainfall in the wet zone during NEM. Similarly, Global warming will support to develop more thunderstorms and severe depressions/cyclones.

With this conclusion, severe thunderstorms can be expected with the global warming in future.

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Heavy Metal, Oil and Grease Pollution of Water and Sediments in Estuarine Lagoons in Sri Lanka: A Case Study in Negombo Estuarine Lagoon

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Abstract Negombo Lagoon is located in the vicinity of a highly industrial and urbanized area. Thus, analysis of heavy metals, oil and grease in the lagoon is of importance at present. The present study has been carried out to assess the contamination levels of heavy metals (Cd and Pb), oil and grease of water and sediments in the Negombo lagoon. Sampling has been carried out in 8 locations. Atomic Absorption Spectrophotometer and standard method of Microwave Digestion Detection by Atomic Absorption Spectrophotometry were used for ~~the~~ heavy metal and oil analysis. Spatial interpolation technique in Arc GIS was used to analyse the data. The Cadmium ion (Cd^{++}) in Negombo lagoon varied between 2.1 and 4.9 ppb and Lead (Pb^{++}) between 17.6 and 48.6 ppb.The concentration of Cd^{++} and Pb^{++} of lagoon water in most locations were close to the upper limit of the inland water standards. High Cd and Pb concentrations were observed in Eastern half of the lagoon. The concentration of oil and grease of the water was between 200 and 5600 µg/l which was extremely high when compared to the minimum quality of the inland water standards. Cd levels of sediments varied between 1002 and 1280 µg/kg while the Pb levels varied between 12,300 and 18,300 µg/kg. Oil and grease concentrations of sediments varied between 30,000 and 3,720,000 µg/kg. Concentration of Cd in sediment when compared to that of water was 477 times higher in its lower limit and 2526.2 times in its upper limit. Likewise, Pb in sediment ~~is~~ was 699 times higher than lower limit and 376 times higher in upper limit. Oil and grease in sediments were

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15times and 66.4 times higher than lower limit and upper limit of the water respectively. The probable reasons for the contamination is lead to be the manmade activities linked to unplanned development with less attention on environment concern.

1 Introduction

1.1 Background

Water is a vital resource to all living creatures and socio-economic sectors (Bhattacharya et al., 2008). It is an essential requirement for industrial development and agricultural production. Furthermore, it is useful in the transportation, energy production and, recreational opportunities while water resources provided different ecosystem services (Bhaduri et al., 2000; Walmsley, 2002; Weerakoon, 2002; Cardoso & Poleto, 2013 and Li et al., 2014). In the recent decades, water resources have been highly contaminated due to anthropogenic behaviors and land utilization practices (Wu et al., 2006; Xiao et al., 2006; Bhattacharya et al., 2008;Yu et al., 2011; Akin et al., 2013).

Estuaries are complex and dynamic environments, which receive large amounts of anthropogenic dissolved contaminants from nearby urban areas and industrial sites (Edmunds et al., 2003). They receive different types of contaminants from both point and non-point sources. Among them, heavy metal contamination in aquatic systems has received considerable attention due to their toxicity, durability and their special depositional properties (Li et al., 2000, Loska & Wiechuła, 2003 and Liang et al., 2004), Toxic metals include mercury (Hg), lead (Pb), cadmium (Cd), chromium (Cr), and copper (Cu) (EPA, 2006). Sources of toxic substances comprise surface water from Municipal and industrial discharges, runoff, atmospheric deposition and geological weathering or agricultural, residential waste products (Bahaduri et al., 2000; Weerakoon, 2002; Cheung et al., 2003; EPA, 2006; Demirak et al., 2006; Liu Cheng et al., 2012; Parveen et al., 2012; Cardoso & Poleto, 2013 and Li et al., 2014). Heavy metals can be effectively accumulated in plants and animals and transferred to human bodies by food chains while ~~and~~ their levels can be increased by biological enrichment. Hg, Cr, Cd, Cu and Pb in environmental water systems may pose high toxicities on the aquatic organisms (Zhou et al., 2008).

Until recent years oil has not been widely considered to be a serious threat to inland waters. Water receives large quantities of oil directly with run-off water which originates from filling stations, industrial areas, roads and disposal of waste oil from inboard engine boats, waste oil released from ships and motorized fishing vessels (Bengtsson & Berggren, 1972; The Gazette of the Democratic Socialist Republic of Sri Lanka, 2006 and Hettiarachchi & Samarawickrama, 2011).Oil pollution has been receiving increasing attention since the middle of the nineteenth century with the increase in tanker operations and oil use and frequent marine tanker collisions and accidents resulting in oil spills (Islam, 2004).

In South America, Asia and Africa, sewage and industrial waste water are often untreated (WHO, 2013). Large amounts of emissions and contaminations of trace elements are of concern at present in Asian developing countries because of the rapid economic growth and increasing population in recent years (Agusa et al., 2007). As a developing country, in Sri Lanka, human settlement patterns during the colonial period have resulted in a high population density, and a consequential concentration of development activities and urban growth, cosmopolitan society engaged in diverse economic pursuits ~~that~~ have an impact on coastal resources. Sri Lanka's coastal habitats have undergone degradation in different degrees during the past resulting in the decline of their resource~~s~~ extents at an unprecedented rate (The Gazette of the Democratic Socialist Republic of Sri Lanka, 2006). A majority of the wetlands in Sri Lanka are facing various threats that are posed by harmful human activities (Kotagama & Bambaradeniya, 2006).

1.2 Environmental Stress in Negombo Lagoon

Negombo lagoon in Sri Lanka is located proximity to the country's main urban and industrial centers and the international sea port and the airport. Therefore, The Negombo-Muthurajawela wetland system has undergone considerable ecological changes over the past few decades (Sellamuttu et al., 2011). Different types of environmental stress have been identified by different researches in this area.

Anthropogenic activities and the development of urban centers on both sides of the Negombo lagoon and infrastructural developments are prominent causes for environmental stress in the lagoon (Environmental profile of Muturajawela and Negombo lagoon, 1991 and Katupotha, 2012). Both unauthorized and authorized land reclamation of this area is another main environmental issue and this has affected the hydraulic regime of the lagoon (CEA, 1994 and Hettiarachchi & Samarawickrama, 2011). The development of tourism industry of the beaches of Negombo, provided ideal frontage for large number of middle grade hotels. This caused unplanned tourism development from the past leading to pollution of coastal waters and habitats, degradation of scenic sites, coastal erosion and user conflicts with the traditional fishery (The Gazette of the Democratic Socialist Republic of Sri Lanka, 2006 and Hettiarachchi & Samarawickrama, 2011). The western region of the Negombo lagoon receives waste from hotels. The sewage systems for many houses in the area and most of the drainage in the Negombo town are diverted to the Negombo lagoon and large quantities of solid and liquid waste are being dumped at various locations in the lagoon resulting in degradation of aquatic environment. Northern region of the estuary is being polluted due to various anthropogenic activities (Indrajith et al., 2008; Hettiarachchi & Samarawickrama, 2011 and Wijesekara & Kudahetti, 2011). The Negombo estuary also receives approximately 90 tons of raw fecal matter annually (The Gazette of the Democratic Socialist Republic of Sri Lanka, 2006). At present some locations in the perimeter of the lagoon are used as solid waste dumping grounds (Idamekorala and Mapa, 2003).

The establishment of the Ekala industrial city and Katunayake free trade zone may have impacts on the water quality of the Negombo lagoon. Central sewage treatment plant of Katunayake export processing zone treats the effluent of 76 industries which are also located in the vicinity of Negombo lagoon. It has been reported that the effluent discharged from all these industries except from the Katunayake export processing zone is not within the relevant CEA tolerance limit specified for the effluent discharged into the surface water (Silva, 1996).

Disposal of waste oil from inboard engine boats have resulted in pollution of water and sediment (Hettiarachchi & Samarawickrama, 2011). Waste oil released from ships and motorized fishing vessels contribute to costal water pollution, and this necessitates remedial action (The Gazette of the Democratic Socialist Republic of Sri Lanka, 2006). The industries established for production of boats, discharge their effluents into the Negombo lagoon resulting in considerable pollution (Wijesekara & Kudahetti, 2011).

As a result, the water quality of Negombo lagoon has deteriorated over the last few decades and these have contributed to the overall degradation of the aquatic environment (Wijesekara & Kudahetti, 2011 and Hettiarachchi & Samarawickrama, 2011). Indrajith et al., 2008 and Chandrasekara et al., 2014 have~~been~~ identified that Cd and Pb levels of water in Negombo lagoon are comparatively high in Eastern half of the lagoon. At present, Negombo estuarine lagoon and Muthurajawela marsh wetland system are categorized and identified as high in overall threatened status considering the magnitude of the disturbances, threats, and pressures (National Wetland Directory of Sri Lanka, 2006) The changes in hydraulic regime, drainage pattern, water quality, degradation of aquatic environment, erosion, sedimentation, floods and health issues are identified as the major impacts (MRI, 1992; Silva, 1996; Ranjan, 2005; Joseph 2011; Wijesekara & Kudahetti, 2011 and Hettiarachchi & Samarawickrama, 2011). This area has been identified as having increased high risk of flooding, heat related sickness, coastal erosion, damage to fishery harbours and anchorages, damage to sea defense structures and breakwaters, damage to near shore infrastructure, salt water intrusion, extended vector habitats with impact on fishery and loss of bio-diversity due to the environment pressure (UN habitat, 2011).

However, significant attention has not been given to study heavy metal and oil and grease pollution in the estuary. Hence, the necessity of studying the heavy metal and oil and grease pollution in water and sediments in Negombo estuary is timely important as there are multiple sources of heavy metal contamination in the vicinity of the estuary (Indrajith, 2008 and Hettiarachchi & Samarawickrama, 2011). Even though the effect of anthropogenic activities on Negombo estuarine lagoon is increasingly high there are only a few scientific researches available on heavy metal in water and sediments. No research has been carried out so far to study oil and grease pollution in Negombo lagoon. Therefore, the purposes of this study is to identify, measure and map the spatial distribution of heavy metal Cd and Pb and oil and grease pollution of water and sediments in the Negombo lagoon.

2 Study Area

The study was conducted in the Negombo lagoon located in the Gampaha district (Fig. 1) in the wet zone of Sri Lanka. The extent of the Negombo lagoon is 3164 ha. It is approximately 12.5 km in length and 0.6 to 3.6 km in width.

The mean depth of the lagoon is approximately 0.65 m. The surface area is 35 km^2 and the volume of the lagoon is 22.5 million m^3. The exchange of water in the lagoon is influenced by tides from the ocean side and fresh water by Dandugam oya and Ja-Ela from the inland side. The lagoon is connected to the Indian Ocean by narrow canals to the north, near Negombo town (Environmental Profile, 1991; CEA, 1994 and Hettiarachchi & Samarawickrama, 2011). Negombo lagoon has been classified as a lagoon under "spit/barrier beach formation" category. The shore is underlined by beach rock (Swan, 1983). The Muthurajawela marsh and the Negombo lagoon have developed during the Holocene period on the Plestocene landscape that existed after the last glacial period (Environmental profile of Muturajawela and Negombo lagoon, 1991). In the main body of the lagoon, the percentage of the silt and clay was in the range of 40% to 99% and most occasions it was well observed 50%. (Hettiarachchi & Samarawickrama, 2011).

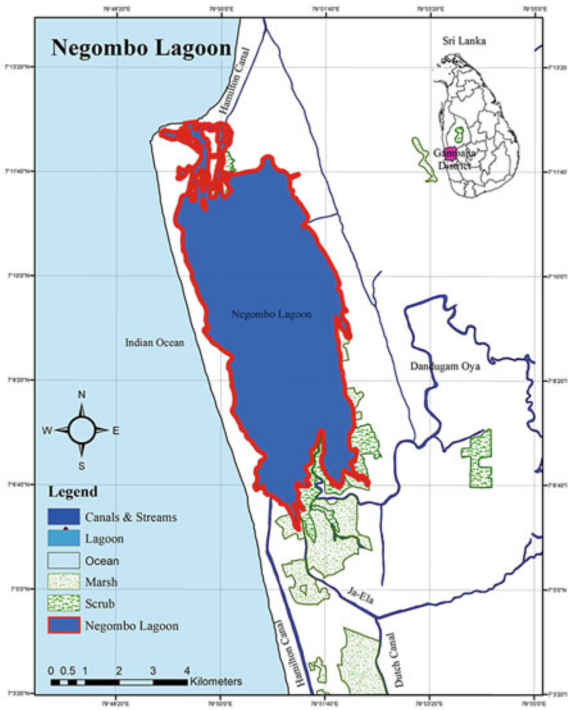


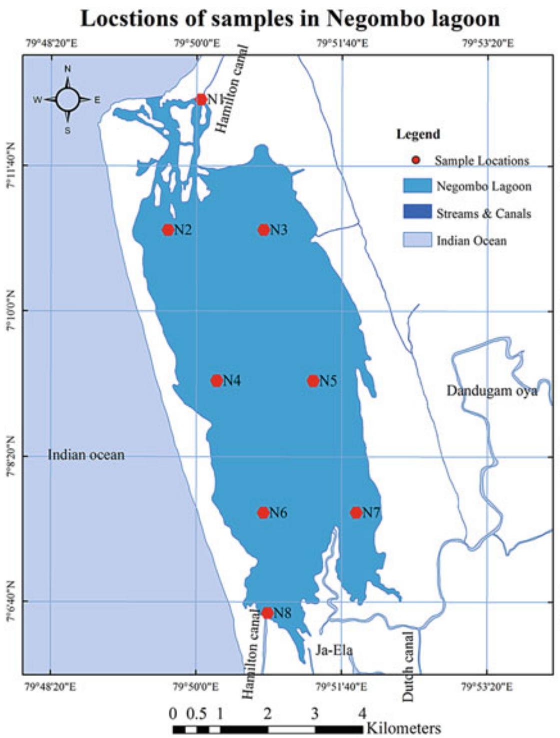
Fig. 1 Location of the study area

3 Methodology

Sampling was carried out in 08 locations of the Negombo lagoon (Fig. 2). Both water and sediment samples were collected from the same points in each location. The sampling was carried out in March 2014 during a relatively low rainfall period and during low tide. Locations of the sampling sites were identified using a 'Magellan eXplorist 610 handheld' GPS (Global Positioning Systems) receiver.

Laboratory analysis has been carried out as per the standards methods of American Public Health Association (APHA) manual: 20th Edition. A standard Ruttner water sampler was used to collect undisturbed water samples and add analytical grade HNO_3 to keep pH < 2. Samples transported to the laboratory, paced in ice soon after the collection. The tests were carried out to detect heavy metals: cadmium (Cd) and lead (Pb) using the Atomic Absorption Spectrophotometer (AA 6300, Shimadzu) at the laboratory of Water Resources Board, Colombo, Sri Lanka. Sediments of the lagoon for heavy metal analysis were collected using Grab sampler and preserved samples immediately after sampling by acidifying with concentrated nitric acid (HNO_3) to pH < 2. Cd and Pb of sediments were analysed according to the standard method of Microwave Digestion (Ethos D) Detection by Atomic Absorption Spectrophotomety (Shimadzu 6650). Oil and grease of the water and sediments were

Fig. 2 Location of samples



analysed according to APHA-5520-B (partition gravimetric) method at the National Building Research Organization, Colombo, Sri Lanka. Three replicate samples were analysed for both water and sediment samples. Proposed Ambient water quality standards for inland waters (Class III waters) (Central Environmental Authority-CEA, 2001) were used to determine the threshold levels of heavy metals. Data analysis was accomplished using SPSS 17.0 software package along with Microsoft Excel. IDW interpolation technique in ArcGIS (version 10.1) was performed to analyse and the spatial distribution of heavy metals, oil and grease in water and sediments were mapped.

4 Results and Discussion

4.1 Overall Results

The concentrations of heavy metals, oil and grease in relation to sample sites are presented in Table 1. Cd levels of all water samples varied between 2.01 and 7.2 µg/l. Cd concentrations of sediments were between 300 and 1800 µg/kg. Pb of the lagoon waters are between 17.6 and 48.6 µg/l and Pb of sediments varied between 12,300 and 18300 µg/kg. The concentration of oil and grease of the lagoon water are between 200 and 5600 µg/l.

Oil and grease concentrations of sediments varied between 30,000 and 3720000 µg/kg. Concentration of Cd in sediment compared to water is 149 times

Table 1 Concentration of heavy metals, oil and grease in water and sediments

Name of the sample	Heavy metals, Oil and grease in water			Heavy metal, oil and grease in sediments		
	Cd (µg/l)	Pb (µg/l)	Oil and grease in water (µg/Kg)	Cd (µg/Kg)	Pb (µg/Kg)	Oil and grease in sediments (µg/Kg)
N1	2.01	17.6	5600	300	18,300	94,000
N2	4.20	35.4	1300	1800	15,900	30,000
N3	3.90	48.6	600	900	14,500	240,000
N4	3.20	45.2	1200	1400	15,400	390,000
N5	7.20	46.3	5700	600	12,300	190,000
N6	3.10	40.9	4200	900	14,800	800,000
N7	4.90	45.1	2800	300	15,300	560,000
N8	2.10	34.9	200	600	17,600	3,720,000
CEA[a] Standard	5	4	100	–	–	–

[a]Central Environmental Authority in Sri Lanka, 2019

higher than in its lowest value, 250 times higher than in its highest value and 222 times higher than its average value (Table 1 and Fig. 3). Pb in sediment is 699 times higher than lowest value, 376 in highest value and 395 times than its average values (Table 1 and Fig. 4). Oil and grease in sediments are 150 times, 653 times and 279 times higher than lower value, upper value and its average value of water respectively (Table 1 and Fig. 5).

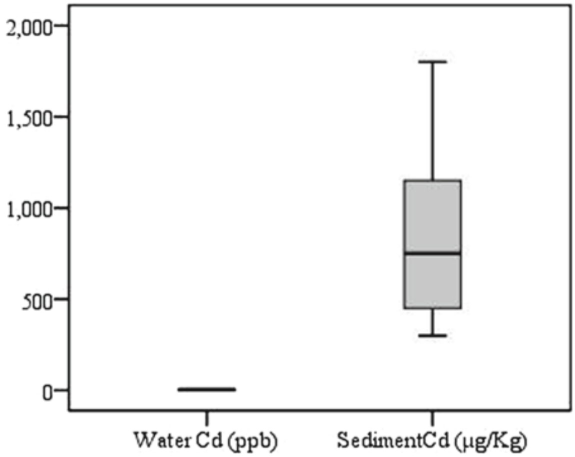


Fig. 3 Cadmium (Cd) concentrations in water and sediments of the Negombo lagoon

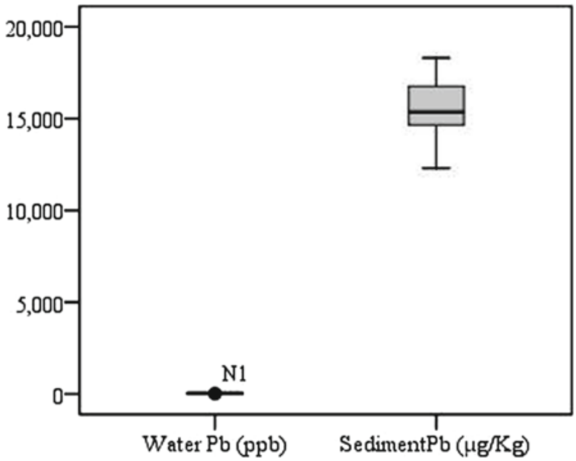


Fig. 4 Lead (Pb) concentrations in water and sediments of the Negombo lagoon

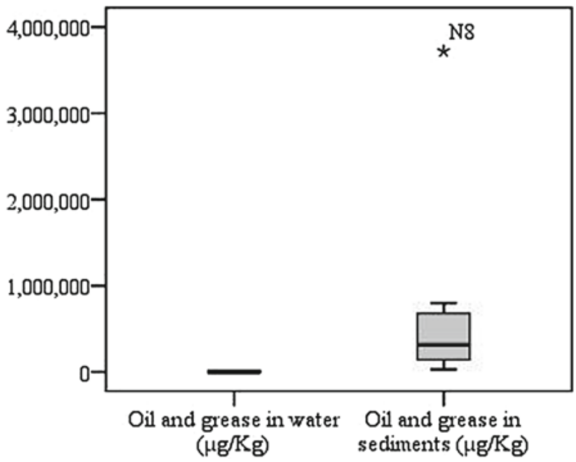


Fig. 5 Oil and grease concentrations in water and sediments of the Negombo lagoon

4.2 Spatial Variations of Cd, Pb and Oil-Grease

The concentrations of Cd of the lagoon water in most locations are close to the threshold level of inland water quality (Quality standard for cd is 5.00 ppb). Sample N7 in the eastern side of the lagoon exceeded the threshold level and sample N5 is almost at the threshold level. Pb of the lagoon water in all locations except N1 is close to the threshold level (Quality standard of Pb is 50.00 ppb). The concentration of oil and grease in water of all the samples are high and above the threshold limit except sample N8 (Quality stand for oil and grease is 300 µg/l) (Table 1). Highest Cd and Pb values are recorded in N2, N3, N5 and N7. All the sample sites are located in North Western and Eastern regions of the lagoon (Fig. 1, Table 1).

Results revealed that there are spatial variations of Cd, Pb and oil and grease concentrations in water and sediments. Spatially the highest Cd levels in water are recorded in the Eastern and Northern Western regions of the lagoon. Western and South Western segments of the lagoon showed comparatively low Cd concentrations in water (Fig. 6a). Concentration of Cd in Eastern half of the lagoon remained constant while the concentration of Cd in Northern and Southern regions fluctuated with the rainfall changes (Chandrasekara et al., 2014). However, the highest Cd levels in sediments were observed in North Western and Western region of the lagoon (Fig. 6b). Indrajith et al., 2008 also identified that Cd levels in both water and sediments were comparatively high in Northern region of the lagoon.

Spatially, high Pb concentrations of water are observed in North Eastern quarter and Eastern half of the lagoon (Fig. a) which agrees with the findings of Indrajith et al., 2008 and Chandrasekara, 2013. The highest concentrations of Pb in sediments ar7e observed in North, North Eastern and South Eastern regions of the lagoon. However, the Eastern segment of the lagoon shows comparatively low concentration of Pb in sediments which shows opposite characteristic of Pb distribution of water (Fig. 7a, b).

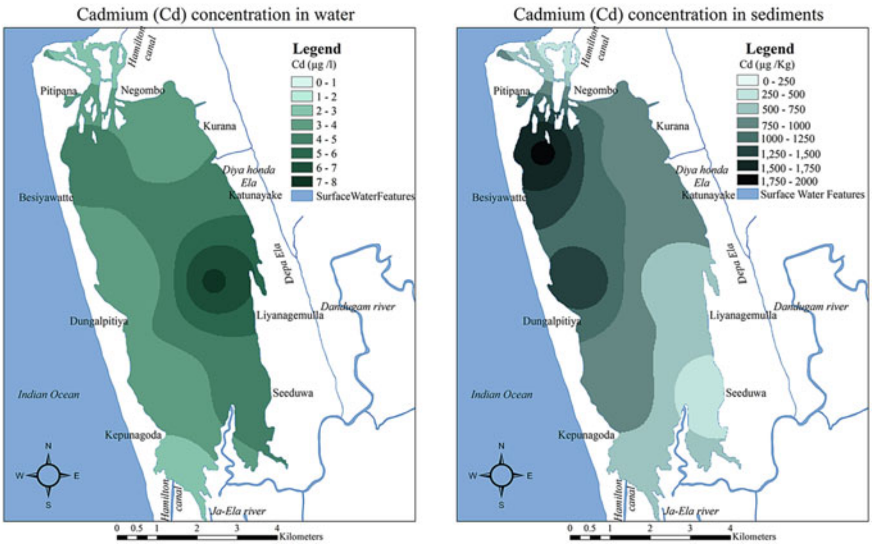


Fig. 6 Spatial distribution of Cadmium (Cd) concentrations in water and sediments

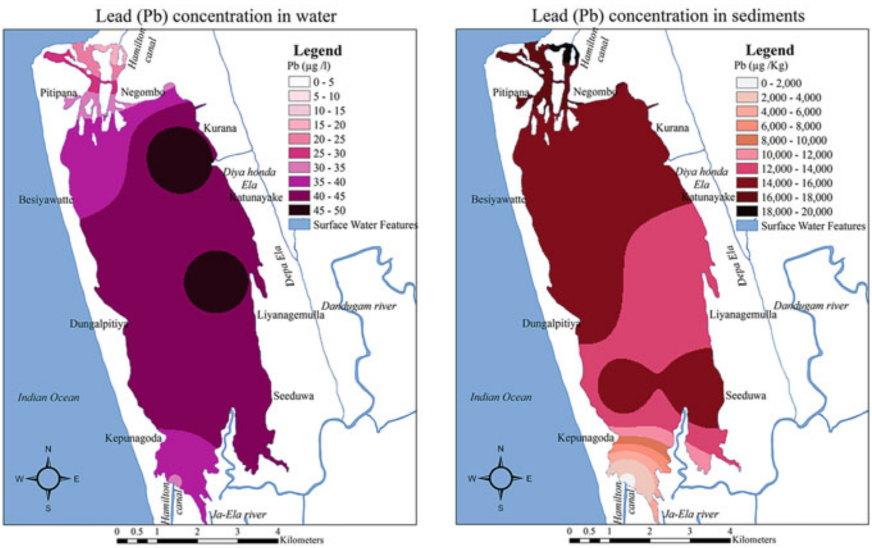


Fig. 7 Spatial distribution of Lead (Pb) concentrations in water and sediments

The high concentrations of oil and grease in water were recorded in the Northern and Eastern regions of the lagoon where boat yards, filling stations and service stations are located and industrial effluents are received. Conversely oil and grease are relatively low in North Eastern, South Eastern, Southern and Western regions of the lagoon (Fig. 8a and b). Spatially, the high concentrations of oil and grease in sediments are recorded in Southern segment of the lagoon which again showed the opposite aspect of the oil and grease concentration of water (Fig. 8a and b).

According to Figs. 6a, 7b and 8a; water in the Eastern region of the lagoon shows high concentration of Cd, Pb and oil and grease. North western segment claimed for high levels of both Cd and Oil-grease in water. High level of Cd, Pb, and Oil-grease in Northern region of Negombo lagoon is due to various anthropogenic activities such as solid waste dumping, waste from industries, slaughter houses, shrimp farms and hatcheries and boat yards, discharge of burned and unburned fuel from motor boats (Indrajith et al., 2008). Eastern region showed high Cd and Pb levels in water. This region of the lagoon receives effluents originated from mainly Ekala and Katunayake industrial processing zone, hotels and housing schemes (Silva, 1996 and Indrajith et al., 2008). According to Figs. 6b, 7b and 8b; concentration of Cd, Pb and Oil-grease in sediments observed high in opposite regions where same parameters have high concentration in water. It may be due to sedimentation. It is a long time process compare to water dynamics. Water of the Negombo lagoon is continuously influenced by tide and fresh water influxes. Thus the concentrations of Cd, Pb and Oil-grease of water can be changed frequently than the concentrations of Cd, Pb and Oil-grease in sediments of the Negombo lagoon.

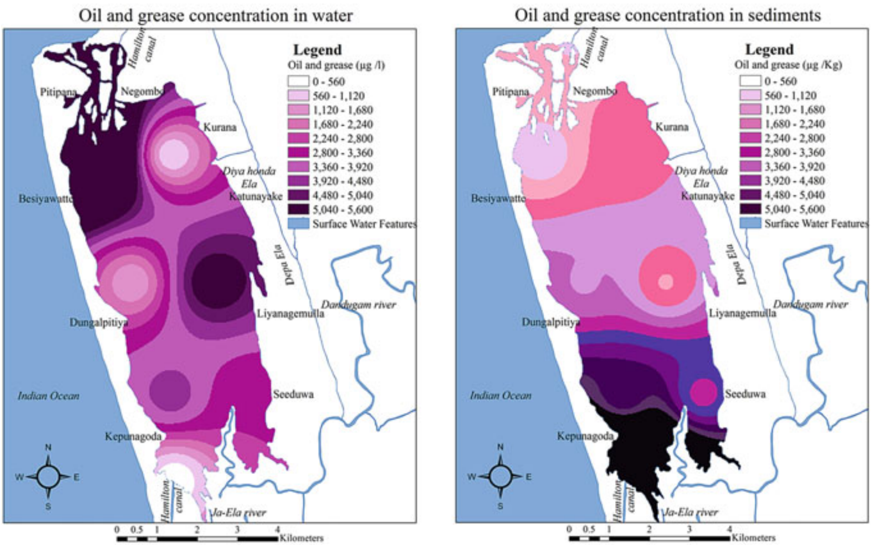


Fig. 8 Spatial distribution of Oil and grease in water and sediments

4.3 Conclusion

Overall Cd levels of water during the study period in lagoon water varied between 2.01 and 7.9 μg/l. Cd levels of sediments were between 300 and 1800 μg/kg. Pb of lagoon waters were between 17.6 and 48.6 μg/l. Pb of sediments were between 12,300 and 18,300 μg/kg. The concentration of oil and grease of the lagoon water were between 200 and 5600 μg/l. Oil and grease concentrations of sediments ~~were~~ varied between 30,000 and 3,720,000 μg/kg. Cd, Pb and Oil-grease levels of water are high in Eastern region of the lagoon. Cd and Oil-grease concentrations are also high in the Nothern regions of the lagoon. Concentration of Cd, Pb and Oil-grease in sediments were observed high in opposite regions where same parameters high in water. Western and South Western segments of the lagoon showed comparatively low Cd concentrations in water. South Western quarter also showed low concentration of Pb in water. As the water of the Negombo lagoon is continuously influenced by tides and waves from the Indian ocean and fresh water influxes from the land side the concentrations of Cd, Pb and Oil-grease of water are dynamic than the concentrations of Cd, Pb and Oil-grease in sediments of the Negombo lagoon. The Negombo lagoon is subjected to intense influences of anthropogenic activities due to rapid industrialization and urbanization in the surrounding area. The estuary is becoming polluted with hazardous chemicals and heavy metals (CEA, 1994). The eastern side of the lagoon receives effluents originated from mainly Ekala and Katunayake industrial processing zone, hotels and housing schemes (Silva, 1996 and Indrajith et al., 2008). Therefore, both water and sediments of the lagoon are affected by non point pollution.

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Co-Management Initiatives in Bush Fire Management—A Case of Belihuloya Mountain Range, Sri Lanka

B. M. R. L. Basnayake, D. Achini M. De Silva, S. K. Gunatiliake, R. H. N. Rajapaksha M. Sandamith, and I. Wickramarathna

Abstract A bushfire can be a real ecological disaster, regardless of whether it is caused by natural forces or human activity. Belihuloya mountain range of Sri Lanka is frequently exposing for man-made bush fires every year during dry season (August- September). Mountain range is home for large variety of flora and fauna and declared as wildlife reserves. Our approach was to investigate the social and eco-nomic impact of bush fires, to develop maps on fire scares and fire risk zones and to develop co-management mechanism to mitigate the bush fires. Qualitative da-ta collection tools were instrumental to collect the data from key areas annually damaged by bush fires. Scattered villages home for both Sinhala artisanal farmers and Tamil estate workers. Both bush fires and wild life pestilence made significant impact on poverty stricken villages. Poor interventions of fragile and scattered formal institutions responsible for disaster management were unable to manage or develop mitigation measures for frequent bush fires. Overlapping mandates, poor coordination and decision making and lack of resources hinders the active participation of formal institutions. Study attempt to investigate the possibility of co-management initiatives on bush fire management and develop strategic interventions of locally based management.

Keywords Bush fire · Co-Management · Sri Lanka

1 Introduction

Natural disasters occur a multitude of entangled societal challenges beyond the realms and capacities of single persons (Bodinab & Nohrstedtc, 2016). Sri Lanka, is an island with rich geography is highly vulnerable to weather related hazards including cyclones, monsoonal rain, and subsequent flooding and landslides (Ministry of Disaster Management, 2019). Forest fire also consider as natural disaster and forest fire includes wild fire, bush fire or grass fire. The event includes all open air

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fires in forests, natural and artificial forest sides, plains, etc. (Ariyadasa, 2001). Bush fires pose a significant threat to human lives and properties (Atkinson et al., 2010). Destruction of natural forests by fires is a serious issue in the world wide and all most all of these bush fires occurred due to man-made causes (Hirschberger, 2016). Country was identified among the three most affected countries in the 2017 estimate in terms of weather-related loss events, ranking second highest on the Climate Risk Index which measures fatalities and economic losses occurring as a result of extreme weather (Eckstein, et al., 2019). Chain of disasters begins with yearly monsoons, and which flows through flooding and landslides cause the most damages in terms of economic impact and human casualties (UNDRR, 2019). In general, landslides are more common in highlands which suffer from loss of vegetation and increased human mediated erosion due to annual forest fires, cultivation of fields and other human development initiatives (Hewawasam, 2010; Turkelboom & Poesen, 2008). Bush fires, landslides, flooding interlinked with household income. Because many of the rural poor communities rely on cash crop products and their land on a high-risk area as their main source of income (Perera, et al., 2018; Prasanna & Gnanatheepan, 2018). Rural regions of the country, low-income households which depend on natural resources as their sole livelihoods and are most vulnerable to financial losses resulting from natural disasters due to displacement, destroyed farm lands, loss of livelihoods (De Silva & Kawasaki, 2018). Lack of infrastructure and transport facilities, inaccessibility due to poor road conditions, poor access to aid, etc. are common in re-mote communities and regions are also often disadvantaged in the aftermath of disasters (MoNPEA & MoDM, 2017; Wickramasinghe, 2019).

Co-management can be defined as organizing the of power sharing for resource management between resource users and different governance levels (Kurien, 2017). Co-management (Paveglio et al., 2018). And in a disaster situation, co management initiatives are most effective when orchestrated within collaborative networks supporting resource sharing, development of joint solutions, power sharing for resource management and coordination (Bodinab & Nohrstedtc, 2016; Kurien, 2017) Level of social capital, which refers to social resources such as trust, norms and networks, are promising social resources to minimize the disaster impacts (Babcicky & Seebauer, 2019; De Silva & Yamao, 2007). In general, disaster preparedness, management, and post disaster rehabilitation are responsibilities of the government and its institutions, NGOs, donor agencies, etc. They are more focus on immediate vulnerabilities and management procedures. Far less is considered the long-term human capacity building and organizational innovations needed to mitigate the issues and manage sustainably (Kurien, 2017; Miller, 2007; Neef et al., 2014) Similar disaster management practices were observed in Sri Lanka. Especially, the bush fire management activities are always focusing on short term measures including control fire with the participation of fire brigades managed by local authorize and armed forces, evacuate the affected communities, provide daily necessities to manage daily life, etc. (Ariyadasa, 2001). Limited focus was made on strengthen the local communities through awareness and education programs, trainings, develop community based innovative mitigation measures, capacity building through providing equipment, etc. Our approach is to examine bush fire risk, identify the socio-economic

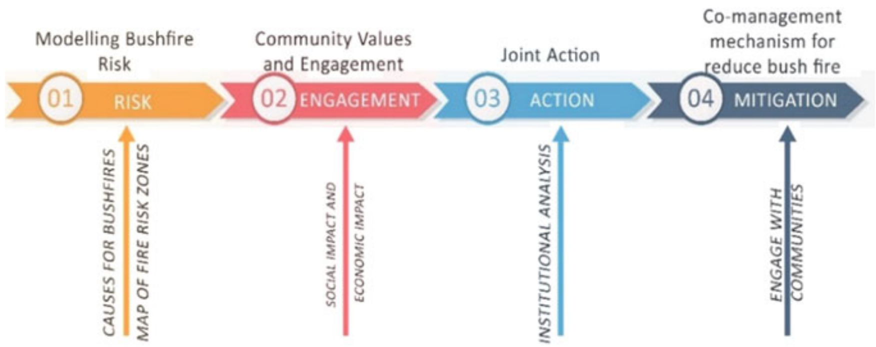


Fig. 1 Conceptual framework of the study

impact and map the bush fire risk zones in Belihuloya mountain area along with examining the drawbacks associated with the existing procedure of bush fire management process and recommending suitable mitigation measures. The results of this study can serve as the basis for initiate co-management action, raising environmental concern and policy interventions in most vulnerable areas in the country.

The concept of the study builds with modeling the bushfire risk by identifying the actual causes and mapping the risk zones a with agricultural lands usage, residential areas and locate the institutions (responsible for manage forest and wildlife re-sources). Conceptual framework discussed in Fig. 1 based on 4 levels. First, identify and measure the bush fire risk, second find out the current level of com-munity engagement in bush fire management, third institutional involvement, find out the mitigation measures developed and implemented jointly (Fig. 1).

2 Methodology

Study was conducted in Imbulpe and Haldamulla DS divisions of Rathnapura and Badulla districts, areas badly affected by natural disasters, of Sri Lanka (Elevation: 589 m and 1237 m; Annual Rainfall: 2832 mm and 1034.7 mm; Mean annual temperature: 27.9 and 23.8 °C). Both locations are an important catchment in central highlands, home for diverse flora and fauna (according to IUCN & MENR, 2007 report; there are 354 indigenous species (90 fauna and 264 flora) and 218 threatened species (74 flora and 144 fauna) are recorded in Badulla and Rathnapura districts) and partially belongs to wildlife sanctuary (Adam's peak Wilderness sanctuary), provided lands for tea plantations, farm lands and human settlements. Further, forest cover comprised of two sections; natural forest with indigenous flora (9337 ha in Imbulpe and 23,390.177 ha in Haldamulla DS divisions) and man-made forest (12,220.05 ha in Imbulpe and 827.7 ha in Haldamulla DS divisions). Identical man-made forests were established in 1970–1989 period under exotic species planting programs with the aim of timber and fuelwood production and they have introduced

Pinus (*Pinus caribaea*), Eucalyptus (*Eucalyptus grandis*), replacing native forests. Case study locations were selected purposely and priority has given to the severity of the incidents, the annually occurring bush fires. Study followed two-fold approach, first, an institutional analysis followed by stakeholder consultations. Filed survey guided by questionnaires were instrumental with key informant inter-views, focus group discussions. Sample profile of institutional analysis composed 06 government institutions, 02 private sector institutions and 02 community organizations. Second approach, filed survey was instrumental to obtain the primary data (bushfire damage, management is-sues, key actors involve in bush fire management etc.) from the local communities. Communities were selected randomly but priorities were given to the communities living in adjacent forest areas, farmlands established closer to forests, worker units of tea plantations, traditional local communities dealing with artisanal farming and livestock raring. Focus group guide was developed based on Participatory Rural Appraisal (PRA) tools. Participatory Rural Appraisal referred to investigation tool of the rural realities that allow for the transformation of knowledge and shared experiences into actions that are oriented towards economically justifiable, socially acceptable and environmentally sound production system (FAO, 2006). Ten focus groups were performed with the participation of five to eight people in Wewekumbura, Niyandagala, Ihalagalagama, Weerakoongama, Walhaputhenna, Ginigathgala, Kirimetiya, Kalupahana, Non Perial estate and Brampton estate. Social map, Venn diagram on institutional analysis, seasonal analysis chart of the bush fires, institutional analysis matrixes were main analytical tools and figures were developed in the field locations with the participation of farmers, local communities who are vulnerable for bush fire incidents. The area map was developed to highlighting the fire risk zones, commercial crop growing areas, forest re-serves, water bodies, houses, responsible institutions using ArcGIS (version10.4). Land use maps of Uva and Sabaragamuwa obtained of Department of Land Use Policy Planning; was the primary sources for developing the map.

3 Results and Discussion

Belihuloya forest reserve; a highly sensitive environmental zone and the magnificent mountain range home for thousands of flora and fauna including endemic, indigenous and threatened species. Unfortunately, surrounding areas are being annually ruined by bush fires during the direst and windy season (July winds/ Poson winds) falls June to August every year. Agriculture including paddy, vegetables, spices and tea is main livelihood of the people while tourism plays an important role in local economy. This area is habitually affected by bush fires, landslides, and droughts which cause recorded damages. In general, most common type of bush fire incidents were manmade or man involved unintentionally and area burnet by a single fire varies from 0.2 to 150 ha with an average of 10 ha. In one hand, disastrous damage is comparably low compared to international scale but annual incidents hurt the country's most important catchments in irreversible way. On the other hand, local communities consider the incidents as annual bush fires, it appears every year, ring of fires spreading throughout, destroy the forests and mountains, and then monsoon rains appear to clear everything and mountains will glow with green grass for cattle herds.

3.1 Institutional Involvement in Bush Fire Management: Institutional Analysis

Bush fire prevention has been the responsibility of many institutions which are located in village, Divisional Secretariat, district, provincial, and national level. Disaster management center and department of wildlife and forest conservation are the key institutions responsible for disaster risk management, empower and capacity building of affected communities, develop mitigation measures and policy actions. Regional level authorities are district disaster management coordination centers, divisional disaster management units, divisional and district forest offices. Figure 2 describe the institutional environment of the research locations.

Most of the institutions were engaging in community level capacity building activities; conducting awareness programs, training programs on disaster management, relief efforts, disaster risk management, preparedness, setting up sign posts, posters, banners etc., prepare action plans, SOPs etc. Institutional involvement levels explain in Table 1. Rating scale was used to score the involvement of each institution and scores varied from 3- high, 2- moderate, 1-low and 0-no involvement.

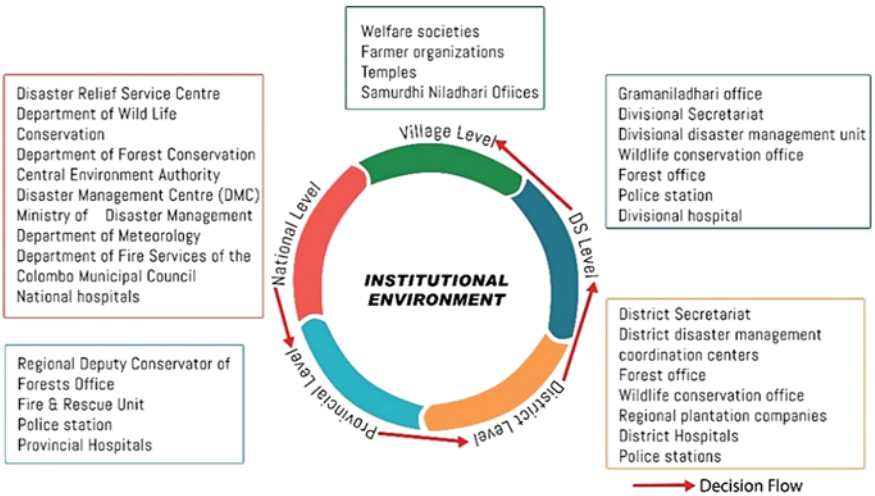


Fig. 2 Institutional environment in bush fire management

Table 1 Institutional involvement

Institutions	Education and training	Capacity Building	Establish community organizations	Awareness building	Prepare action plans, SOPs	Conduct pre-disaster meetings
Divisional secretariat	Moderate	Moderate	Low	Moderate	High	High
Divisional disaster management unit	Moderate	High	High	High	High	High
Wildlife conservation office		Low	Low	Moderate	High	Low
Forest office	Low	Low	Low	Moderate	High	Low
Fire & rescue Unit		Low	Low	High	High	Low
Police station	Low	High	Moderate		Low	Moderate

High involvement ▬ Moderate involvement ▬ Low involvement ▬

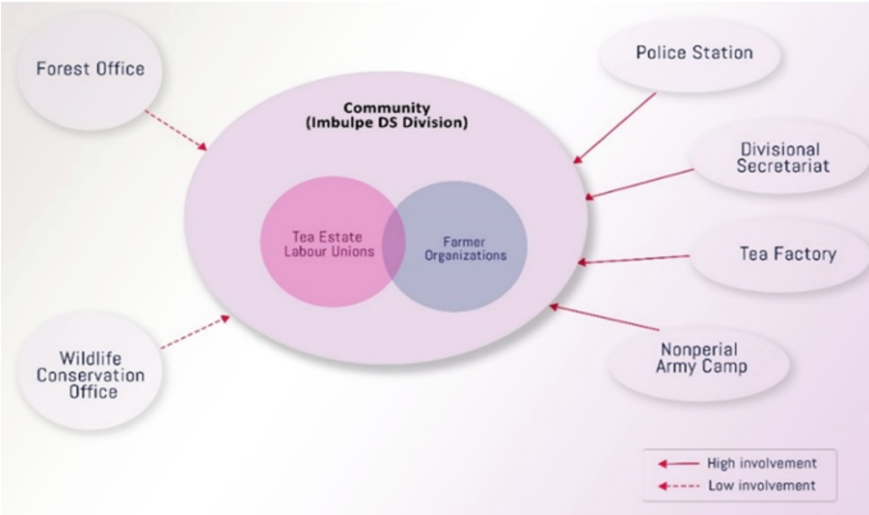
No involvement ▭

In general, villagers used to inform the incidents to nearest police station or police hotline and or Gramaniladhari, government office at village level for precautionary measures. While estate workers follow their usual routine, inform the authorities though their manager. Figure 3a and b shows the institutional involvement in both locations and its impact on community.

Figure 4 illustrate the Venn diagram of inter-institutional relationship in the community and arrows symbolize the strength of relationships. It is clear that divisional forest officers and wildlife conservation officers are not highly involving in this process while, disaster management officer, police stations, nearest army camp and labors and mangers of tea factories are highly involving in mitigating bush fire and takes legal actions against culprits. Further, the volunteer environmental conservation organizations also playing an important role in bush fire management by re-plantation, awareness building, display sign boards etc.

Community organizations were not established to cater the need of disasters or bush fire management. There are several village level organizations, established for community welfare and religious activities and there is a potential to link disaster management into already established societies or operate as separate section of establish societies.

A



B

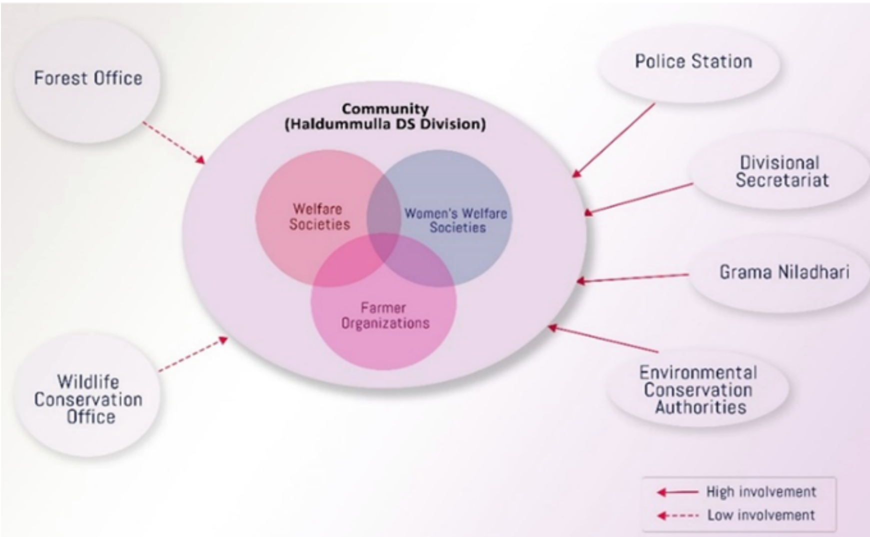


Fig. 3 **a**. Social organizations venn diagram: imbulpe DS division, **b**. Social organizations Venn diagram: Haldamulla DS division

3.2 Bush Fires, Communities, and Collective Action

Findings highlighted that fires destroy about 90 ha of forest cover in Rathnapura district and about 650 ha in Badulla district annually. And also, this mountain range mainly covered by the Eucalyptus (*Eucalyptus grandis*) and Pine (*Pinus caribaea*)

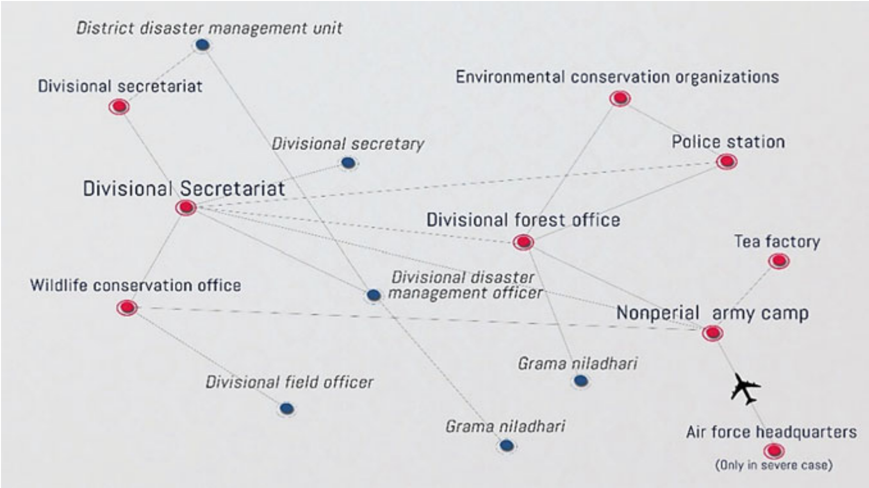


Fig. 4 Inter-institutional relationship Venn Diagram

plantations managed by the Forest department where patches of local vegetation are available in some locations. Pine and Eucalyptus plantations are highly susceptible for bush fires and act as vehicle to spread the fires and making the fires worst. With reference to the department of forest conservation (2017) nearly 55% of all fires are reported from pine plantations while 20% is from eucalyptus plantations. Further, tea plantations are directly exposing to bush fires annually and damages recorded were significant. Results revealed that several reasons are responsible for bush fires; such as; setting fire for agricultural purposes, hunting, setting camp fires by tourists, careless fire handling by the dwellings (throwing cigarette butts or matchsticks to the forest), and manmade fires to divert the attention of officers from illegal gem mining and drug dealing.

The season of bush fires mainly falls in February–March and August-October with favorable weather conditions; high temperatures, less rainfall, low humidity and windy conditions. Dry mix evergreen and sub mountain forests are predominant in this area. Until the reason past villagers used to set firers purposely in the month of August expecting rains and then regenerate their grass lands. Manmade fires are legally prohibited and strict enforcement of law manage the situation. On the other hand, an area is top ranked tourist destination for hiking and camping. Therefore, managing manmade fires are much difficult to control. In general, 5 days take to control the fire incident and this varies with the size of the incident. All bushfire incidents bring uncountable socio-economic problems. Table 2 discusses the socio-economic and environmental impacts.

Adverse socio-economic impacts including loss of indigenous wildlife habitats and plants, loss of valuable timber resources, reduction in forest cover, creating unhealthy living conditions due to higher smoke and ash generated from the fires.

Table 2 Socio-economic and environmental impacts of bush fires

Issue	Rank: Imbulpe	Rank: Haldamulla
Losing indigenous wildlife habitats and plants	I	I
Loss of valuable timber resources	II	I
Reduction in forest cover	I	I
Creating unhealthy living conditions due to higher smoke and ash generated in fires	II	II
Lack of drinking water	II	I

(Level of the issue: I—Prominent, II—Moderate, III—Least)

Further, communities were suffering from lack of drinking water supplies. Majority (about 90%) of the villagers were belongs to the lower income group (Average monthly income 107.25US$). Agriculture is the main livelihood option and rain fed farming was common in both locations. Paddy, tomato, beans were common crops and occasional Chena cultivations were practiced in buffer zones and in the forest. Further, backyard production is significantly contributed to their daily food supplies. On the other hand, estate workers are depending on their daily wages mainly and backyard production for extra income. Of the study locations 0.5–05 ac of average tea lands are annually exposed for bush fires and estimated economics loss is around 105 USD- 525 USD. Table 3 present the social map on income categories.

An area map (Fig. 5), was developed by using land use map of Uva and Sabaragamuwa province. Key features are land use types, fire risk area, buffer zones, farmlands, community settlements and institutions. Tea is main agricultural activity followed by paddy and other crops.

Bush fire prevention has been the responsibility for many institutions including Forest Department, Divisional Secretariat, Disaster Management Center, Police

Table 3 Social map on income classification

Class	Criteria	No. of households
Rich	Income >50,000 LKR Having permanent job Having own vehicles/land/house/livestock	28 H.H
Middle	Income <30,000 LKR Having permanent job Having own bicycle, motor bicycle or three wheel/ small land/house/livestock	60 H.H
Poor	Income <25,000 LKR Not having permanent job Not having own vehicle/land/house/livestock	125 H.H
Poorest	Income <20,000 LKR Working for daily wages Not having own vehicle/land/house/livestock	55 H.H

Source Field survey, 2019

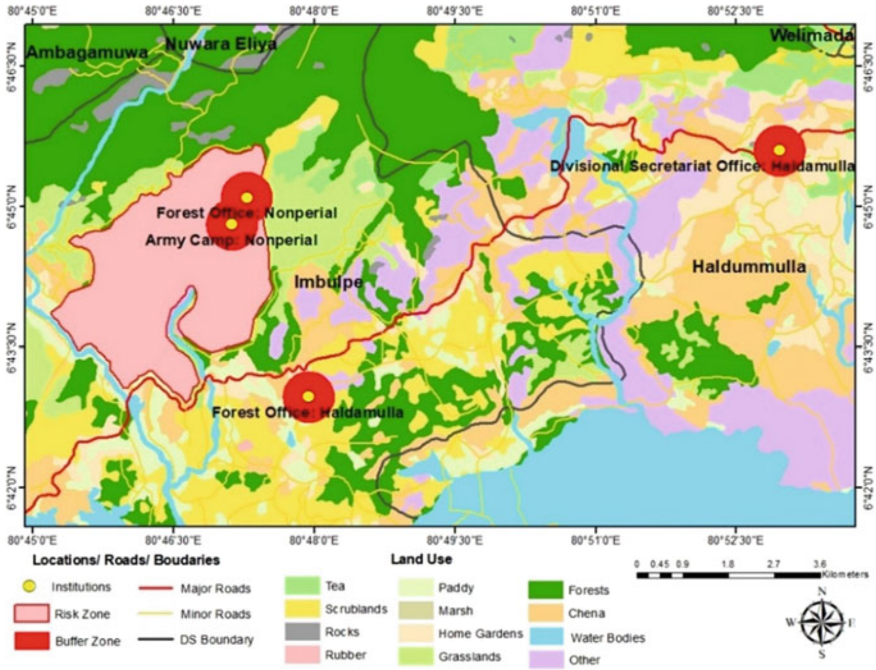


Fig. 5 High risk areas of bushfires in the Imbulpe and Haldamulla DS division

Stations. However, these institutions located more than 10 km away from the risk zones and there were no village level responsible society. Decision making in bush fire prevention, management, and develop mitigation measures are complicated, varies in area to area and no proper and solid mechanism established so far. Absence of organized community level engagement in fire management always worsen the situation and volunteers and central government authorities have to involve heavily on manage the disastrous situations. Poor resource status of the institutions (human and physical) delayed fire control and usually it takes 5–10 days.

In general, male members are volunteers in bushfire management than female counterparts of them. Unfortunately, there is no proper awareness, and training mechanism on fire prevention, management and mitigation. Villagers are using traditional and inefficient methods to manage the fires annually, and fires make huge losses environmentally, socially and economically. Adding water or soil, cutting firebreaks, land management by removing the raw materials for any potential bushfire such as dried leaves, etc. are the key methods practiced by communities. Inefficient methods as well as poor public participation always ended up with huge damage. Therefore, it is vital to raise public awareness, particularly among those people who live close to or in forested areas. Community values and engagement is a best strategy which is used in most of the disaster proven countries [24]. Building or strengthening community organizations are essentially needs to consult extensively with communities, and other institutional stakeholders. Scientific involvement in developing bush fire management measures and awareness building starts from the kinder gardens and schools are essential components in the programs. Village level societies need to take the leading role in bush fire management with the shared delegation of power and authority from the public institutions. Community engagement also builds relationships and helps to develop shared understanding of the risks and how best to mitigate them. In this process, maintaining past records is also essential to make correct decision on communities and places at particular risk of bushfires. ICT would cater to share the information among interested parties and facilitate on developing mitigation measures. Implementing fire danger rating system (Emergency Management Australia, 2000) is another strategy which forecasts the potential for a forest or grassland fire by using drones' images and GPS locations and is based on seasonal drought, recent rainfall, temperature, relative humidity and wind speed. According to this system we can develop rating system as extreme fire danger, high fire danger, moderate fire danger and low fire danger.

4 Conclusion

Belihuloya mountain range is home for large number of locally as well as globally important flora and fauna. Natural resources are highly vulnerable for the man-made bushfires annually, during the August–September dry season. Institutional landscape of disaster management comprised of government and NGOs but there were none of the community level organizations responsible for natural hazard management. Respective authorities pay poor attention towards the natural dis-aster management, there is a hidden but critical socio-economic impact has been caused by bush fires annually. There is an important need to establish community level organizations to manage the fires and other disasters. Bush firers brought adverse socio-economic and environmental impacts, including destruction of biodiversity, extinction of flora and fauna, deterioration of soil, ecosystems resulting in erosion and loss of soil fertility, loss of wildlife habitat and threaten the wildlife, reduction in forest cover, creating unhealthy living conditions due to smoke and ash generated in fires, resulted in a lack of drinking water and contamination of the water resources. Fire risk maps show that potential risk area and location of households of the adjacent communities and established institutions. Establish and empower community level organizations in high-risk areas and delegation of power and decision-making authority is recognized as one of the key strategic involvement. Further, implementation of the fire danger rating system using GIS technology was identified as a positive strategy. Co-management mechanism would help to develop sustainable solution to bush fires in Belihuloya mountain range.

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Drowning Prevention and Water Safety Sri Lanka: Challenges and Recommendations

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Abstract Sri Lanka is a tropical Island located in the Indian Ocean with inland waters. Sri Lanka has one of the worst rates of drowning deaths in the world with 3 deaths on daily average, totalling over 800 drowning deaths per year according to Sri Lanka Drowning Report 2014 and 2020. According to the World Drowning Report, 2014 the country is internationally ranked 12th in a comparison of 61 countries, and 10th highest among the low and middle income countries. However, the 2020 drowning report revealed that Sri Lanka has improved to reach 14th, due to the implementation of Drowning Prevention and Water Safety Action Plan from 2017–2020. The Disaster Management Centre (DMC) of Sri Lanka has taken a holistic approach with the technical support from the local and international lifesaving institutions. Initially, DMC has established the national steering committee for drowning prevention and water safety and five working committees, which include public sector, private sector, NGOs and INGOs to prepare a National Plan of Action (NAP) on Drowning Prevention and Water Safety for Sri Lanka. The NAP is aimed to utilize existing resources with an approach to turn the same problems into opportunities. It is also aimed at creating an economic environment through tourism, and to provide basic swimming training for schools including a "Swim for Safety" program in the curriculum. Other objectives of the NAP are to ensure the safety of water related activities while building the capacities of first responders enhancing employment opportunities and promoting water-related recreational activities through tourism. Media has to make the community aware with adequate information. Existing regulations are empowered and new regulations are imposed to prevent deaths due to drowning and water related activities through proper monitoring. The aim of this paper is to create a platform to share the Sri Lankan experiences and lessons learned

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from developing and practicing "National Drowning Prevention and Water Safety Action Plan 2017–2020".

Keywords Drowning · Prevention · Water · Safety

1 Introduction

Drowning is a significant cause of death and injury worldwide, as highlighted in the global report on drowning (WHO, 2014). While it is difficult to compare drowning rates internationally due to inconsistencies in the completeness and quality of data, it is recognized that drowning rates are highest in many Low-and Middle- Income Countries (LMIC).

In 2014, an estimated 372,000 people died from drowning, making it the world's third leading unintentional injury killer and there are approximately 42 drowning deaths every hour, every day (WHO, 2014).

Sri Lanka is a tropical country surrounded by the blue waters of the Indian Ocean and with inland waters including lakes, reservoirs, rivers and water falls known throughout the world. Sri Lanka has one of the worst rates of drowning deaths in the world with more than 3 deaths on average every day, totaling over 850 recorded drowning deaths per year according to Sri Lanka Drowning report of 2014.

Sri Lanka was equally ranked 12th by comparing unintentional drowning rates across 61 different countries in a study of Lin et al (2015). The latest available three year 2016–2018 mortality data as shown in Table 1 where health statistics of 60 countries were compared (WHO, 2014). It was 14% reduction when compared to 2005–2007 average number of drowning deaths.

Despite drowning been an anthropogenic Hazard, natural hazards like floods due to extreme rainfall during Monsoons in Sri Lanka and the Tsunami have caused the highest number of fatalities due to drowning. Every year floods cause enormous damage all over the world (Jonkman, 2005). Floods caused by extreme rain events are becoming a serious risk of drowning in many countries in the world. Between 1998 and 2017, more than 526 000 people died worldwide from drowning (Eckstein et al., 2019; Van Beeck et al., 2005).

The Disaster Management Center (DMC) of the Ministry of Disaster Management has taken a holistic approach to address drowning in Sri Lanka, with the technical

Table 1 Drowning deaths from year 2016–2018

Year	Reported deaths by Gender		Total deaths reported
	Male	Female	
2016	615	145	760
2017	539	139	678
2018	668	160	828

Source Department of Police, Sri Lanka support from the Life Saving Association of Sri Lanka (LSASL), Life Saving Victoria (LSV), Australia and the International Lifesaving Federation (ILSF). As first steps, DMC has established the National Steering Committee for drowning prevention and water safety with five working committees in 2017, which include officers of Government, NGOs, INGOs, volunteers as well as the private sector. The National Plan which was developed in the workshop on Drowning Prevention and Water Safety Sri Lanka, held from 3–7 July 2017 is aimed at utilizing the available resources with a positive approach that turns the very same problems into opportunities that will make the community safer creating an improved economic environment through tourism and job creation at the same time. Following strategies were carried out by the relevant stakeholder agencies in line with National Drowning Prevention and Water Safety Action Plan, 2017–2020;

1. Delivering Swimming and Water Safety Education
2. Communicating and managing information for water safety
3. Providing lifesaving and water safety services
4. Conducting water safety research and development
5. Maximizing economic benefits for tourism through safe water related activities
6. Developing regulations for governance of water safety and drowning prevention.

Within this context, the aim of this paper is to; emphasize the importance of mitigating drowning deaths in Sri Lanka, create a platform to share Sri Lankan experiences and lessons learned from developing and practicing" National Drowning Prevention and Water Safety Action Plan 2017–2020".

2 Data and Methodology

To find out the effectiveness of drowning mitigation activities carryout by varies stakeholders in Sri Lanka regarding the "National Drowning Prevention and Water Safety Action Plan", some data were collected from the primary sources. Data were also collected directly from the relevant mandated government agencies. Primary data were collected by using two deferent ways by conducting stakeholder workshops, and Interviews. A fully structured interviews were carried out with authorized personnel of all relevant mandated organizations.

Identification of drowning incidence trends for the past few years is important to understand the trend and to determine who is having risk of drowning, where and how drowning deaths occurred. Therefore, this study includes unintentional drowning deaths reported in Sri Lanka from 2001–2018 excluding 2008 and 2015 based on the availability of primary data. Year 2008, drowning data were not available due to civil war in Sri Lanka. In 2015, data was not available due to inaccessibility of reports.

Data on drowning deaths and injuries from 2006–2018 were collected from "desinventar" disaster database of Disaster Management Center (DMC) of Sri Lanka.

Data on unintentional drowning deaths from 2001–2014 were collected from Registrar General's Department of Sri Lanka. The Registrar General's Department extracts the data based on the World Health Organization's International Classification of Deceases (ICD) reporting system. Specifically, the supplementary classification of external causes of injury, accidental drowning and submersion, accident to watercraft causing submersion, and other accidental submersion or drowning in water transport accident. Deaths due to natural causes, assaults, suicide, or homicide were not included.

The information on unintentional drowning deaths of 2016–2018 was collected from the Sri Lanka police. This information from 44 police areas across 25 districts in Sri Lanka includes cause of death, gender, location of the water source, the residence of the victim, whether within or outsides the police area, or whether the victim is a foreign visitor.

The actual downing figures may be different from the actual drowning deaths. For example, in only 81.9% registered deaths, the cause of death was recorded as drowning deaths and 28% registered deaths were having ill-defined causes for all mortality data for Sri Lanka in the year 2006 (WHO, 2019).

Results are grouped by sex, age and location.

3 Results

Annual drowning deaths reported in Sri Lanka from year 2001–2018 are shown in the Fig. 1. It varies with slightly decreasing trend.

Annual number of deaths by drowning in Sri Lanka for the years of 2008 and 2015 cannot be found in primary sources. Sri Lanka has one of the worst rates of drowning deaths in the world with more than 3 deaths on average every day, totaling over 855 records drowning deaths per year from year 2001–2014, where 755 average drowning deaths from year 2016–2018 showing a decreasing trend of 14%.

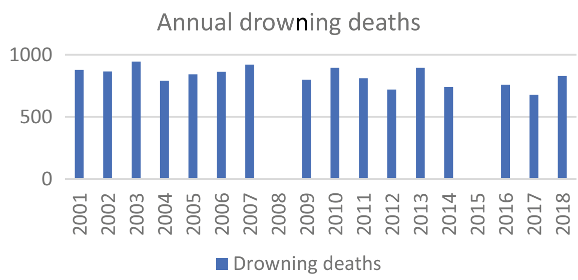


Fig. 1 Annual drowning deaths in Sri Lanka from 2001–2018

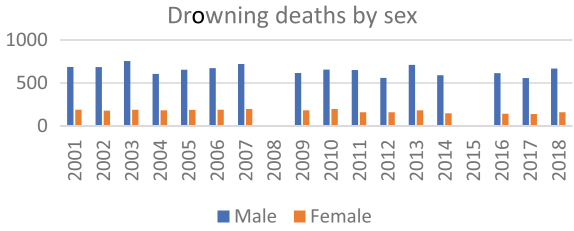


Fig. 2 Annual drowning deaths in Sri Lanka by sex, from year 2001–2018

3.1 Sex

Annual drowning deaths reported in Sri Lanka by sex, from 2001–2018 are shown in Fig. 2.

Males were four times more likely to drown than females according to the primary data of annual drowning deaths from year 2001–2014, whereas males were 3.5 times more likely to drown from 2016–2018, which is a decrease from the previous period.

3.2 Age

To identify which age group is having the greater risk of drowning compared to all the age groups, primary data of average number of drowning deaths by age groups from 2012–2014 were analyzed and presented in Fig. 3**.**

Drowning information by age was only available from year 2012–2014 in the primary data collection and that had shown highest number of deaths among the 25–44 years age group and 45–64 years age group, with just over 200 deaths per year. Considering the age and sex, together, young males have more risk of drowning incidents due to various reasons such as abuse of alcohol, ignorance, carelessness and water related recreational activities in unknown waters. In addition, lack of awareness, lack of warning sign boards in risk locations, inability to swim, lack of floating and lifesaving skills and a dearth of trained life savers as well as search and rescue teams for response.

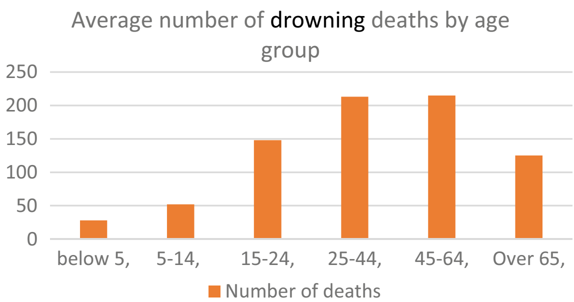


Fig. 3 Annual average number of drowning deaths by sex in Sri Lanka from 2012–2014

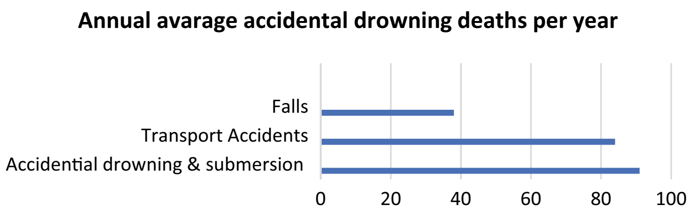


Fig. 4 Annual average accidental drowning deaths among children in the age groups of below 5 and 5–14 years in Sri Lanka from 2004–2014

Annual average accidental drowning deaths among children in the age groups of below 5 and 5–14 years in Sri Lanka 2004–2014 is shown in Fig. 4. Accidental drowning and submersion rank the first among three accidental drowning death incidents in Sri Lanka while transport accidents come in second with falls having the third rank.

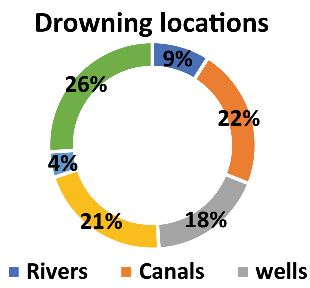
This may be due to lack of supervising by the parent, lack of awareness, lack of swimming skills, floating ability, unprotected water wells, ponds, pools and tubs.

3.3 Location

Sri Lanka is an island nation with all types of inland and coastal waters. Nationally top locations for drowning incidents are shown in Fig. 5.

Canals have the greater drowning risk (22%) than coastal waters (21%) followed by wells (18%) and rivers (9%).

Fig. 5 Percentage of drowning deaths by the location of waters in Sri Lanka from 2016–2014



4 Issues

There needs to be much more national and international attention focused on drowning known as the "silent killer", given the limited data available on its true scale and the effects of heavy death toll on families, communities and economies.

The estimated death toll is all the more alarming because official data categorization methods for drowning exclude intentional drowning deaths (suicide or homicide) and drowning deaths caused by flood disasters and water transport incidents (including those where vessels carrying migrants, refugees and stateless people capsize during so-called irregular transport on water).

Primary source of" desinventar" having drowning data as boat capsizing, drowning, heavy rain and flood, therefore calculation and integrating this information was difficult.

Some stakeholder agencies with their organizational mandate were implementing several activities to prevent drowning in Sri Lanka. But due to lack of integrated common approach, the result were not clearly marked. Furthermore, lack of drowning related data and common data sharing platform was an issue.

5 Conclusion and Recommendation

In this study it is shown that there is a slight decreasing trend in annual death toll due to implementation of some strategies of the "National Drowning Prevention and Water Safety Action Plan 2017–2020", but still there is the need more improvement in governance, institutional coordination, advocacy, resource mobilization by revamping the plan of actions and strategies with multi sectorial approach.

Maintaining a drowning surveillance system and developing a common data sharing platform will be of definite help in developing the comprehensive drowning risk profile for Sri Lanka. Based on the risk profile, above mentioned six strategies can be implemented to mitigate the impact due to drowning incidents.

By analyzing the risk of drowning by sex and the age groups it was evident that most young males were the victims of drowning incidents due to various reasons such as water related recreation, alcohol abuse and carelessness. However, those deaths of the bread winners of the family not only impacts the family but also the national economy.

Children under 14 years of age also have a greater risk of drowning due to lack of swimming ability, unprotected waters, carelessness and lack of supervision by their parents.

One of the major steps is to provide basic swimming training for all through the "swim for safety program" by making it mandatory for schools to include Swimming for Safety into the curriculum. Children can be taught basic swimming in inland waters successfully. In addition, children should be given appropriate and adequate awareness on risks and dangers involved in swimming in the lakes or on our beaches to save more lives and create more development opportunities related to water.

Strengthening the capacities of the rescuers of Sri Lanka Navy, Army, Air force, Coastguard, Police, Civil Defense Service and Volunteers creating employment opportunities as first responders of pool and beach safety will also be an important issue to be addressed.

It is evident in the present context that the media is eager in feeding the public with death tolls of how many died in which river/lake/beach around the country every day. Going forward, media has to play a major role to make the community aware, since collective measures with adequate information and expertise can bring effective results in mitigating the deaths by drowning.

Empowering existing regulations and imposing new regulations to prevent deaths due to drowning and water related activities through proper monitoring mechanism should be another matter to be considered in this regard.

In terms of waters, Sri Lanka is having all types of inland and coastal waters. Therefore, we need to have beaches, rivers, wells and other waterways with protection, safety measures and trained lifeguards of international standard. It is also important to have communication and marketing strategies to promote Sri Lanka as a safe water recreation destination.

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Regional Drought Monitoring for Managing Water Security in South Asia

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Abstract Drought is the most complex climate-related disaster issue in South Asia and has affected 1.46 billion people with an economic loss of over 7 billion USD in the last 56 years. South Asia is challenged with water, food, and energy security due to growing populations, incomes, resource degradation, and vulnerability to climate change. Monitoring of drought and associated agricultural production deficits using meteorological and agricultural indices is an essential component for drought preparedness. Remote sensing offers near real-time monitoring of drought conditions and IWMI's has implemented South Asia Drought Monitoring System (SADMS) in 2014 as an online platform for drought early warning and support in drought declaration. This chapter explores the use of composite drought indices implemented in Google Earth Engine (GEE) and evaluates the crop yield variability during drought years. The study provides a rapid overview of drought-prone conditions that could enhance the present capabilities of early warning systems and enable science based policies for addressing water security in the agriculture sector and develop a drought response plan between water supply and demand, significantly increasing the vulnerability of regions to damaging impacts of drought events.

1 Introduction

Drought is one of the most devastating natural disasters in the world and affects more people than floods and any another natural disaster because of the large-scale impact on people, agriculture and economic losses. Climate change is clearly a driver that will affect food and water security for the foreseeable future and their impact

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increases as a growing population dependence on available water resources and on agricultural systems. Owing to global warming, droughts have been occurring more frequently over expanding areas in recent years, especially in semi-arid regions of the northern hemisphere (Dai, 2013; Liu et al., 2015; Yao et al., 2018). Droughts have been classified into meteorological, agricultural, hydrological, and socioeconomic droughts (Liu et al., 2018; Wilhite and Glantz, 1985). The below Fig. 1 provides a better understanding on the consequences of drought and how they affect human demands and values of water, ranging from food production to ecosystem services across scale and time.

South Asia is extremely vulnerable to climate-related disasters and a significant portion is exposed to more than one type of hazard. Drought in South Asia has far ranging impacts on all natural hazards from human and livestock death toll to economic losses. As per EM-DAT (2020) a total of 48 major drought events reported in South Asia between 1990 and 2020 (May) with an affected population of over 750 million and economic damages estimated at 6.57 billion USD. Droughts are projected to be more frequent and prolonged in the arid and semiarid areas of India, Pakistan and Bangladesh, while landslides and glacial lake outburst floods will be more frequent in the mountain regions of Bhutan and Nepal (ADB, 2010).

Being able to accurately identify and monitor drought is therefore of considerable importance. Thus, monitoring the severity and its impact of drought is critical for drought risk mitigation by policy makers in improving the food security

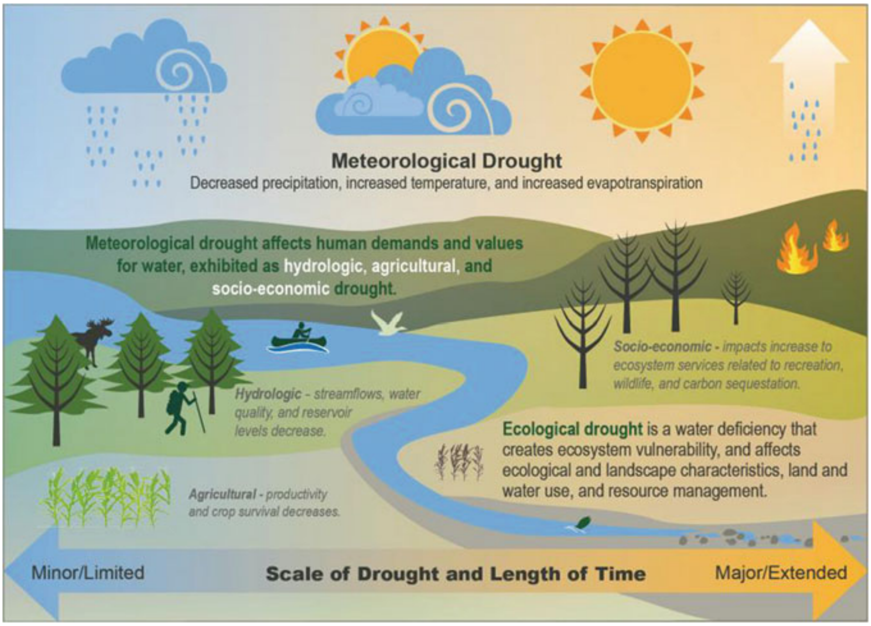

Fig. 1 Impact chain framework of drought types and its impact. *Source* United States Department of Agriculture

and enhancing livelihood among smallholder farmers. In South Asia, traditionally the station-wise weather data were used to derive meteorological drought indices for drought monitoring and early warning. But sparse meteorological network and lack of timely availability of weather data always hinders the accurate and timely monitoring of regional drought.

Over the last few decades, studies have focused on drought concepts (Whilhite & Glantz, 1985), monitoring (Amarnath et al., 2019; Damberg & AghaKouchak, 2014), predictions and early warning (Hao et al., 2014), impacts (Liu et al., 2018), adaptation and mitigation (Kaye & Quemada, 2017; Mottaleb et al., 2017) and vulnerability (Sharma, 2017). From the review it is clear several studies highlight the importance on the composite products rather than standalone indices such as NDVI, NDWI or others. Similar other composite index being the Integrated Drought Severity Index (IDSI) from IWMI which is adapted within the South Asia Drought Monitoring System (SADMS), Global Integrated Drought Monitoring and Prediction System (GIDMaPS), Multivariate Standardized Drought Index (MSDI), Global Land Data Assimilation System (GLDAS), United States Drought Monitor (USDM) and others. Other indices such as Composite Drought Evaluator eXperiment (CoDEX) which is a composite blend of different hydrologic indicators, which are assigned values consistent with U.S. Drought Monitor drought categories. Example of composite indices namely the Integrated Drought Severity Index (IDSI), which captures the nature and characteristics of current drought conditions at the regional and country levels.

The IDSI drought product has been tested in several countries including the South Asia (Amarnath et al., 2019), Senegal (World Bank, 2020) and MENA region which incorporate Vegetation health anomalies from the Normalized Difference Vegetation Index (NDVI) anomaly from MODIS which captures the state of stress within crops relative to average conditions for the month, the Surface temperature anomaly from MODIS highlighting whether conditions are warmer/cooler than usual for that month, Precipitation anomalies captured through the Standardized Precipitation Index (SPI) using CHIRPS data highlighting whether it is wetter/drier than usual for that month, Soil moisture anomaly from the Copernicus ASCAT product generated through the LIS model capturing whether the rooting zone soil moisture is drier/wetter than usual for the month and finally the Actual evapotranspiration anomaly from MODIS, which is a classical example to consider all possible variables to explain drought severity. Recently, IWMI has received Geospatial excellence award in promoting drought surveillance system for South Asia. To expedite the whole system, the drought monitoring platform now has been shifted to cloud system with collaboration with Google. Google provides an extraordinary geospatial cloud computing platform called Google Earth Engine (GEE). GEE is a cloud-based geospatial platform[1] that offers various opportunities for accessing near-real-time and historic satellite data to monitor natural resources. Users can access the products through a simple web interface without the need for proprietary based software, or high-speed internet connection. GEE provides a rich data catalogue of several geo-spatial datasets at global scale. User can develop

[1] https://earthengine.google.com/

their own codes to identify and/or monitor earth system processes using GEE application program interface (API) which is available in Python and JavaScript. Apart from the process the raster or vector data, the GEE API has the capacity to report statistics as table and graph for further analysis.

In this chapter, we will briefly review some commonly used drought indices with a focus on the developing integrated drought indices using remote sensing and cloud platform using GEE. A unified framework implemented for the South Asia drought monitoring and assessment and presented with case studies. Conclusions and recommendations are presented in the last section.

2 Method

2.1 Developing Multi-Sources Composite Drought Index

Remote sensing data provides useful information on the spatiotemporal distribution of droughts and well established to monitor and evaluate the drought conditions, and most of these indices are based on long-term atmospheric and vegetation information (Cao et al., 2019; Martínez-Fernández et al., 2015). Among those indices, the Vegetation Condition Index (VCI), Temperature Condition Index (TCI), Precipitation Condition Index (PCI) (Hao et al., 2015) and Soil Moisture Condition Index (SMCI) are few examples those are widely used to monitor agricultural droughts (Bhuiyan et al., 2006; Kogan, 1995). There are few more indices which were developed to assess the agricultural drought based on the relationship between the vegetation indices (VIs) and land surface temperature (LST), such as the Temperature Vegetation Dryness Index (TVDI) (Sandholt et al., 2002) and Vegetation Supply Water Index (VSWI) (Rebel et al., 2012), while the indices like Vegetation Health Index (VHI) (Kogan, 1997), have been developed by combining VCI and TCI using a linear weighted method, while some indices. Similar to VHI, Scaled Drought Condition Index (SDCI) combines the PCI, TCI and VCI using empirical weights 0.5, 0.25 and 0.25 (Du et al., 2013). Based on the constrained optimization method (Hao et al., 2015), the Optimised Vegetation Drought Index (OVDI) was developed to assess the agricultural droughts, by combining VCI, TCI, PCI and SMCI. Moreover, some of the agricultural drought indices, such as the SWD index (Torres et al., 2013), Soil Water Deficit Index (SWDI) (Keshavarz et al., 2014), and the Modified Soil Water Deficit Index (MSWDI) (Vicente-Serrano et al., 2010), consider the deficit of the soil moisture. However, they either consider only soil water content or take into account the water supply and demand relationship between the soil water and Potential evapotranspiration (PET). Therefore, multiple indices with multiple combinations have been used to understand and quantify the drought in different parts of the world. However, drought caused by multiple factors or drivers, such as precipitation, soil moisture and evapotranspiration and the response to those drivers should be assessed by considering all of those relevant processes as indicators based on the availability of the datasets. However, the majority of the existing agricultural drought models were assessed by considering either few of those factors. Therefore, it is necessary to develop a method to better assess agricultural droughts by considering precipitation (input to the system), soil moisture (storage of the system), actual ET (loss to the system) and VCI (vegetative response of the system) altogether. In a nutshell, the study aims to develop a comprehensive agricultural drought index, named the Integrated Drought Severity Index (IDSI), based on the water balance method (Fig. 2 and Table 1). Thus, IDSI also overcome the drawback of the single indicators and

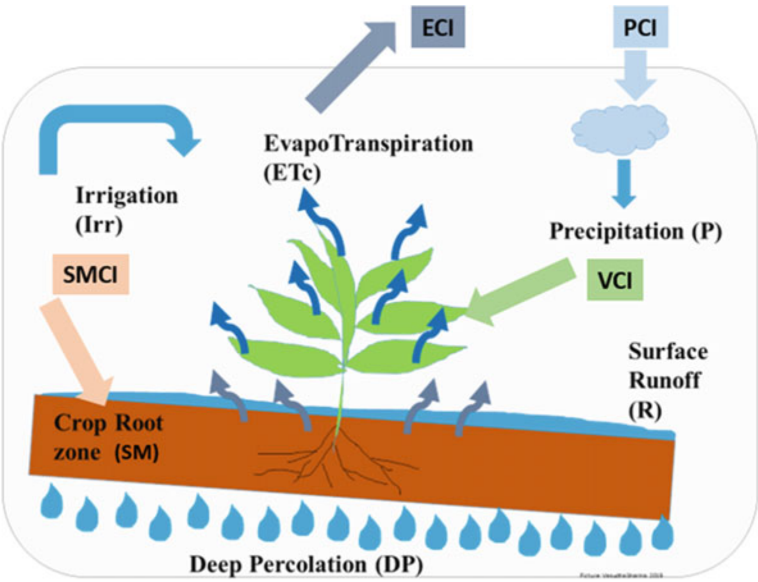

Fig. 2 Conceptual flowchart of land-water interaction to determine drought impact

Table 1 Data used in developing IDSI product

Parameter	Data	Source
NDVI	MODIS (MOD13Q1)	https://developers.google.com/earth-engine/datasets/catalog/MODIS_006_MOD13Q1
Precipitation	CHIRPS	https://developers.google.com/earth-engine/datasets/catalog/UCSB-CHG_CHIRPS_DAILY
ET	MODIS (MOD16A2)	https://developers.google.com/earth-engine/datasets/catalog/MODIS_006_MOD16A2
Soil moisture	FEWS NET Land Data Assimilation System (FLDAS)	https://developers.google.com/earth-engine/datasets/catalog/NASA_FLDAS_NOAH01_C_GL_M_V001

reliable enough to predict drought condition. The purpose of IDSI being a composite indicator would be helpful in determining the drought condition more reliably.

IDSI ranges from 0 to 100. The classification of IDSI into drought classes was developed by analyzing the frequency distribution of IDSI values throughout the region. Based on the Cumulative Distribution Function (CDF) analysis, IDSI thresholds were set and classified into four classes (“extreme”, “severe”, “moderate” and “Non-drought”) represents agricultural stress to healthy condition.

2.2 Implementation of IDSI in GEE

In the last decade, Earth observation (EO) satellites and different global models have generated large amounts of geospatial data that are freely available for science and society. To support to store and analysis/process those datasets and other demands like powerful interactive visualization platform, novel technologies have been developed majorly based on cloud computing platform with combination of distributed database systems, MapReduce systems and web services to access and process big EO data. GEE as a geospatial cloud platform has various functions to perform spatial, spectral and time series operations ranging from spatial mathematical operations to machine learning framework (Gorelick et al., 2017). Various pixel-based spectral operations, which have high potential to be implemented in parallel on cloud architecture, are included in GEE. Implementing a state-of-the-art algorithm like multi-sources composite index IDSI on GEE is a great step towards an improved the near real-time drought monitoring framework to support drought early warning system. Such state-of-the-art monitoring capabilities with time series of estimation both from satellite observations and model predictions. is very useful even for non-technical users who may be interested to investigate drought conditions of large areas. The codes are written in GEE’s JavaScript API (application programming interface). Both Earth Engine public data catalogue and external data sources (like Land Cover, boundary shape file, etc.) were invoked in the algorithm to produce the final IDSI maps. Thus multi-sources with various data type can be ingested in the GEE platform.

2.3 Standardized Precipitation Index (SPI)

The SPI is calculated based on the probability of precipitation for any time scale[2]. In SPI, precipitation is the only input parameter. The SPI can be computed for different time scales, provide early warning of drought and help assess drought severity. It is less complex than many other indices.

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[2] https://library.wmo.int/doc_num.php?explnum_id=7768

Precipitation is known to follow an asymmetric frequency distribution, with the bulk of the occurrences at low values, and a rapidly decreasing likelihood of larger precipitation totals. There are a number of such positively-skewed analytical distributions (Guttman, 1999). The distribution for the SPI adopted by McKee et al. (1993), is the incomplete gamma distribution. SPI algorithms analyze the input data to optimally estimate two key coefficients which govern the transformation, and the observed precipitation data are transformed to Gaussian (normal) equivalents. The transformed precipitation data are then used to compute the dimensionless SPI value, defined as the standardized anomaly of the precipitation. To calculate SPI index, the study used satellite-derived GPM IMERG precipitation product to compute 3-month SPI from 2000 to 2020 using Python scripts for the region of South Asia.

2.4 Crop Yield Anomaly Calculation

The yield data were standardized to remove the suppression difference to produce the crop yield anomaly (CYA) using the following formula

$$CYA = \frac{Y_i - \bar{Y}}{\sigma Y}$$

where, CYA is the standardized unit yield, Y_i is the crop yield in the year *"i"* for one province, $\bar{Y}$ is the average yield and σY is the standard deviation. In general, the CYA values should be very low during the drought season and high during the wet season.

3 Drought Monitoring Over South Asia: Case Studies

3.1 Agricultural Drought Monitoring Using IDSI

Time-series earth observation datasets play a key role in assessment of agricultural drought. Here are the examples of IDSI a composite index for Afghanistan highlighting the agricultural stress developed using GEE. IDSI provides up-to-date information on drought conditions for early warning to early action and to forecast potential drought impacts. Figures 3 and 4 show the spatial distribution of drought condition of Afghanistan and South Asia in the year of 2018. Further IDSI classes were evaluated for two years 2018 and 2020. The IDSI performed well in capturing historical drought events.

In the case of Afghanistan, North-Western and Western provinces are mostly affected by drought over the last twenty years. Drought trends of these region very efficiently captured by IDSI during March –April of the historical drought years.

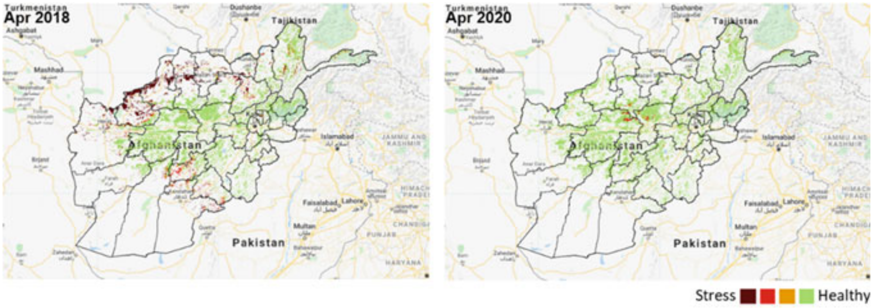

Fig. 3 Spatiotemporal pattern of (IDSI) for Afghanistan during the normal year (2020) and drought year (2018) processed in GEE cloud platform

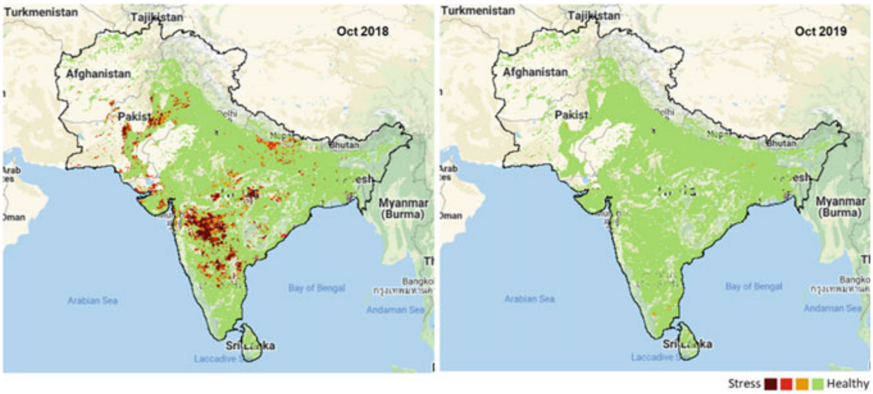

Fig. 4 Spatiotemporal pattern of (IDSI) for India during the normal year (2019) and drought year (2018) processed in GEE cloud platform

Similar performance of IDSI was experienced in different parts of South Asia based on the cropping season of the respective region or country. Figure 4 clearly shows the drought signal of 2018 in the Maharashtra and other southern state of India. Compared to 2018, 2019 shows a normal year almost all part of the region. These results were further compared with SPI maps in the next section.

The above section described the development and successful implementation of an IDSI to monitor the onset, duration, extent, and severity of drought, which resulted in the 2014 launch of the South Asia Drought Monitoring System (SADMS) online platform[3].

[3] https://dms.iwmi.org

3.2 *Meteorological Drought Monitoring Using SPI*

Occurrence of drought cannot be monitored by comparing the relative rainfall observed in various stations over a large area. To overcome these limitations, the use of spatial SPI for drought monitoring was adopted to monitor regional drought scenario. SPI is an excellent means that gives indication of the drought characteristics like onset, severity, and spatial extent. Based on the calculation of SPI drought index, it is found that there was severe drought condition happened in the specific locations over different time.

Southwest monsoon over large part of India has shown natural climate variability with multi-decadal epochs of dry and wet period. When southwest monsoon rainfall is below normal, SPI values were –1 or less and thus in moderate, severe or extremely severe drought categories. During the period 1901–2015, there were four years, viz., 1965, 1972, 2002 and 2009, when SPI was in the extremely dry category and out of that 1972 was the most (Guhathakurta et al., 2017). Figure 5 shows the spatial distribution in SPI -3 months of October 2018 and October 2019. Low SPI values are seen over major part of the South Asia including western and southern part of India, large part of Pakistan and Bangladesh in the month of October 2018 while same month of 2019 shows wet condition in those regions. SPI values have shown significant decreasing trends indicating increasing drought scenario over many districts of east Maharashtra, Andhra Pradesh, Karnataka, Gujarat, Rajasthan and Madhya Pradesh of India, several districts in Sindh and Baluchistan regions of Pakistan, and northern western districts of Bangladesh. With seasonal variability in rainfall pattern, a detail SPI analysis for the 2018 drought year for Afghanistan was evaluated. The SPI analysis between December to April being the critical rainfall season in Afghanistan. Figure 5 shows spatial map 3-month SPI for the October month was compared in reference to drought (2018) and normal year (2019).

The main finding of this analysis is that changes in rainfall affect drought in two ways. The first identification is the representation of very low SPI-3-month values during the month of December due to the delay of onset of the rainy season, i.e.

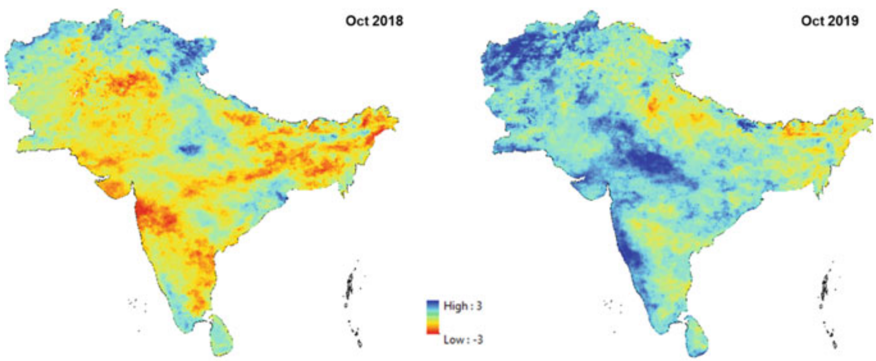

Fig. 5 Spatial distribution of SPI-3 of Oct 2018 (**left**) and Oct 2019 (**right**)

the decrease in rainfall from October to December. For example, during the 2018 droughts, the lowest 3-month SPI values were shown in the previous year (Dec) 2017. This indicates a decrease in the required rainfall in the early stages of crop cultivation. The second identification is the decrease in 3-month SPI during the months when maximum rainfall is expected, which is February and March of the year. For example, low 3-month SPI values during 2001 and 2008 droughts are represented in February and March. Since positive 3-month SPI values were observed in both December 2018 and February 2019, it was possible to accurately predict 2019 as a drought-free year by aggregating the SPI values at province level (Table 2). The provinces shown here are the areas where most of the rain-fed agriculture is practiced.

The maps shown in Fig. 6 were generated using the calculated drought thresholds through the CDF to understand the spatial distribution of the drought based on the 3-month SPI values at the country level. The results of 3-month SPI show that the drought in 2018 affected all provinces of Afghanistan with varying degrees of severity, with more than 75% of the provinces in the extreme drought category. However, no province was affected by the drought in 2009 and Northern, North Eastern and North Western Provinces were mostly affected by the drought in 2008.

Table 2 Historical drought and non-drought events detected by the February and December 3-month SPI values

Province	3-month SPI (Dec)				3-month SPI (Feb)			
	2000	2007	2017	2018	2001	2008	2018	2019
Badghes	−0.58	−0.24	−2.19	0.43	−1.27	−1.78	0.16	2.00
Balfch	−0.84	−0.41	−1.72	1.67	−1.95	−1.82	−0.29	2.75
Faryab	−1.08	0.13	−1.91	0.63	−1.78	−1.59	−0.31	2.26
Hirat	0.26	−0.14	−2.38	0.23	−0.98	−1.89	0.12	2.08
Jawzjan	−0.80	−0.01	−2.05	0.98	−1.90	−1.98	−0.36	2.75
Kunduz	−0.39	−1.21	−1.77	1.52	−1.84	−1.47	−0.46	2.01
Sar-e-Pul	−0.97	−0.36	−1.56	1.72	−1.70	−1.35	0.55	2.65

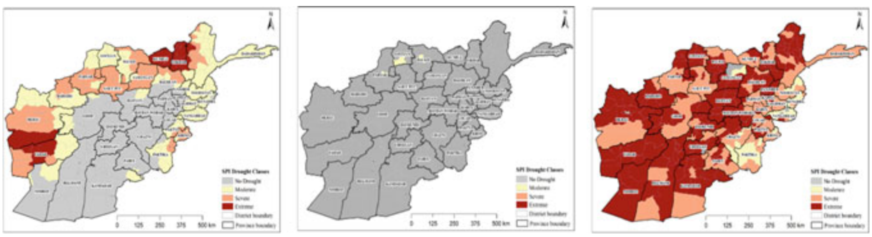

Fig. 6 Spatial distribution of country threshold derived from the SPI-3 of December of 2007, 2009, and 2018

3.3 Comparison of IDSI, SPI and Crop Production

Correlation analysis among IDSI, SPI-3-month and yield anomaly was also carried out in this study to get clarity between the drivers and response of drought. As shown in Table 3, the CYA was calculated using the wheat production data provided at the provincial level from 2006 to 2019 based on available production data. These production data are provided separately for Irrigated and Rain-fed wheat crop. This calculation shows that the CYA value of wheat crops shows a higher negative value during the drought years and a higher positive value during the non-drought years for both Irrigated and Rain-fed crop.

The entire agricultural (IDSI and CYA) and metrological (SPI 3 month) drought monitoring parameters described above sections clearly mapped the droughts in the years of 2001, 2002, 2008, 2011 and 2018. In addition, Table 2 shows that the CYA value of both rain-fed and irrigated crops showed high negative in 2008, 2011 and 2019. It clearly states that the provinces were affected by a severe drought in those years. This means that the validity of the drought monitoring parameters is very high and the months selected to use for different indicators are well accepted. The CYA data were analyzed separately with SPI-3-month and IDSI to further confirm the strength of the drought indicators and to understand how reliably those indicators can be used for Afghanistan (Fig. 7 and Table 3). In order to generate the scatter plot (Fig. 7), data used to represent both drought years (2008, 2011 and 2018) and non-drought years (2009, 2010 and 2014).

The results show that IDSI and SPI-3 month are individually well correlated (0.84) with the yield anomaly and can able to capture the variation of crop production of drought year and Non-drought year (Table 3). The SPI reflects the drought intensity and duration significantly and is sensitive to the precipitation distribution. The SPI values at different time scales (like 1-month, 3-month, etc.) have different physical meanings. The SPI values in a relatively short-time scale reflects the change of short-term soil water content to a certain extent, which are of great significance for agricultural production, specifically those crops whose water intake is high. The SPI values in a relatively long-timescale reflect the long-term stream-flow variation and play an important role in the management of the reservoir (Wu et al., 2018). SPI-3-month is more sensitive to the onset and persistence of droughts during a year or crop season; meanwhile, it reflects the characteristics of short-term meteorological droughts, which can be strongly related to agricultural drought (Yao et al., 2018). Thus, SPI-3 month was used here. In case of IDSI, it is a composite index combining the effect of the meteorological drivers like precipitation and temperature with the soil moisture and vegetation conditions compared to the long-term situation of those variables. Therefore, IDSI reflects the current crop condition compared to the historical record by considering the meteorological inputs. Thus, IDSI is also showing a higher correlation with CYA.

Table 3 CYA values for Balkh, Badghes, Faryab, Hirat, Jawzjan, Kunduz and Sar-e-Pul Provinces between 2006 to 2019 for both rainfed (R) and Irrigated (I)

Year	Batkh		Baddies		Faryab		Hirat		Jawz	an	Kunduz		Sar-	e-Pii
	R	I	R	I	R	I	R	I	R	I	R	I	R	I
2006	1.00	0.33	1.58	0.52	1.33	0.34	0.37	−0.25	0.63	1.08	−0.71	−0.59	1.47	0.19
2007	1.09	0.40	1.51	1.19	1.19	0.34	1.50	−0.25	0.97	1.28	−0.52	−0.54	1.34	0.31
2008	−1.01	−0.30	−1.09	0.05	−1.42	−0.44	−1.01	−1.26	−1.01	−0.57	−1.29	−1.35	−1.07	−0.42
2009	1.01	0.40	1.41	2.23	1.44	0.44	1.39	0.21	1.37	0.95	−0.04	−0.13	1.12	0.39
2010	0.07	0.79	0.12	0.10	1.02	2.22	−0.30	−0.72	0.61	0.88	−0.01	0.57	0.43	1.65
2011	−1.24	0.79	−1.09	0.62	−1.24	−0.34	−0.30	−0.36	−0.63	−0.77	−1.22	−0.34	−1.52	−0.62
2012	1.22	0.64	0.66	0.41	1.36	−0.21	−0.16	−0.55	2.16	1.52	0.12	0.31	0.32	0.72
2013	1.36	1.04	0.75	−0.04	−0.43	−0.68	1.86	−0.40	0.52	0.14	0.41	0.23	0.81	2.05
2014	1.05	0.97	−0.47	−1.03	−0.58	−0.59	−0.26	−0.31	0.40	−0.93	2.32	2.14	0.75	0.32
2015	0.02	1.09	−0.44	−1.39	−0.88	0.34	−0.05	0.33	−0.65	−0.07	0.90	1.14	−0.68	−0.24
2016	−0.49	−0.15	−0.26	0.36	-0.03	0.88	−0.07	1.96	−0.99	−1.26	0.67	−0.03	−0.71	−0.35
2017	−1.25	−1.93	−0.34	−0.59	0.12	1.24	−0.53	1.51	−1.15	−0.71	1.46	0.32	−1.11	−1.80
2013	−1.39	−1.35	−1.65	−1.53	−1.12	−1.93	−1.66	1.05	−1.20	−1.32	−1.35	−0.01	−1.37	−0.75
2019	−0.67	−1.10	0.46	0.00	−0.86	−0.34	0.45	0.75	−0.42	0.78	−0.52	0.22	0.71	−0.05

The highlighted year represents the severe drought condition in those provinces

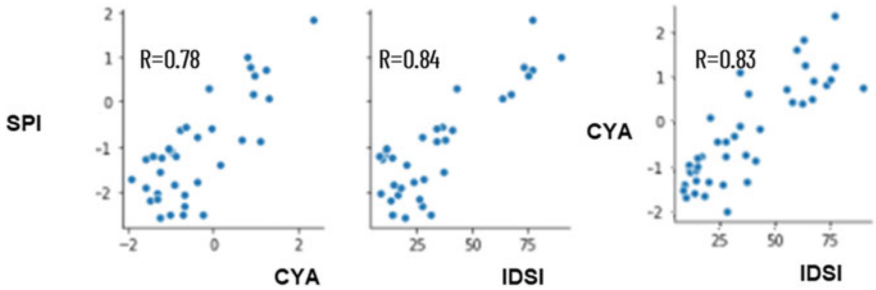

Fig. 7 Scatter plot and histogram of the major drought indicators (of selected years of 7 provinces)

4 Impact of Drought on Water Security

According to UN-Water, water security is defined as the "capacity of a population to safeguard sustainable access to adequate quantities of and acceptable quality water for sustaining livelihoods, human well-being, and socio-economic development, for ensuring protection against water-borne pollution and water-related disasters, and for preserving ecosystems in a climate of peace and political stability." In the past few decades, the definition of security is limited to the focus on military risks and conflicts and in recent years the scope of security has been broadened in addressing human security and its achievement through development. Water fits within this broader definition of security—embracing political, health, economic, personal, food, energy, environmental and other concerns—and acts as a central link between them."

Drought risk measures where droughts are likely to occur, the population and assets exposed, and the vulnerability of the population and assets to adverse effects. Higher values indicate higher risk of drought (Fig. 8). The figures highlights that most parts of the South Asia will experience medium to high drought severity with competing demands and high variability in water availability. There is a clear need to develop holistic integrated water resource management (IWRM) and in combination of inter-sectoral and basin approaches to ensure IWRM are suitable for efficient management of water in landscapes of various natural and agricultural ecosystems. In the coming years, IWRM will be seen as a key prerequisite for ensuing climate resilience and water security in the region.

5 Drought Adaptation Measures

Reducing current vulnerability to climate risks such as drought is necessary for adapting to climate change in the future. SADMS is an important tool in this regard. Vulnerable farmers experience climate change primarily through increases in the frequency and severity of extreme events. These climate shocks such as drought, flooding, or heat waves erode smallholder farmers' livelihoods through loss of assets,

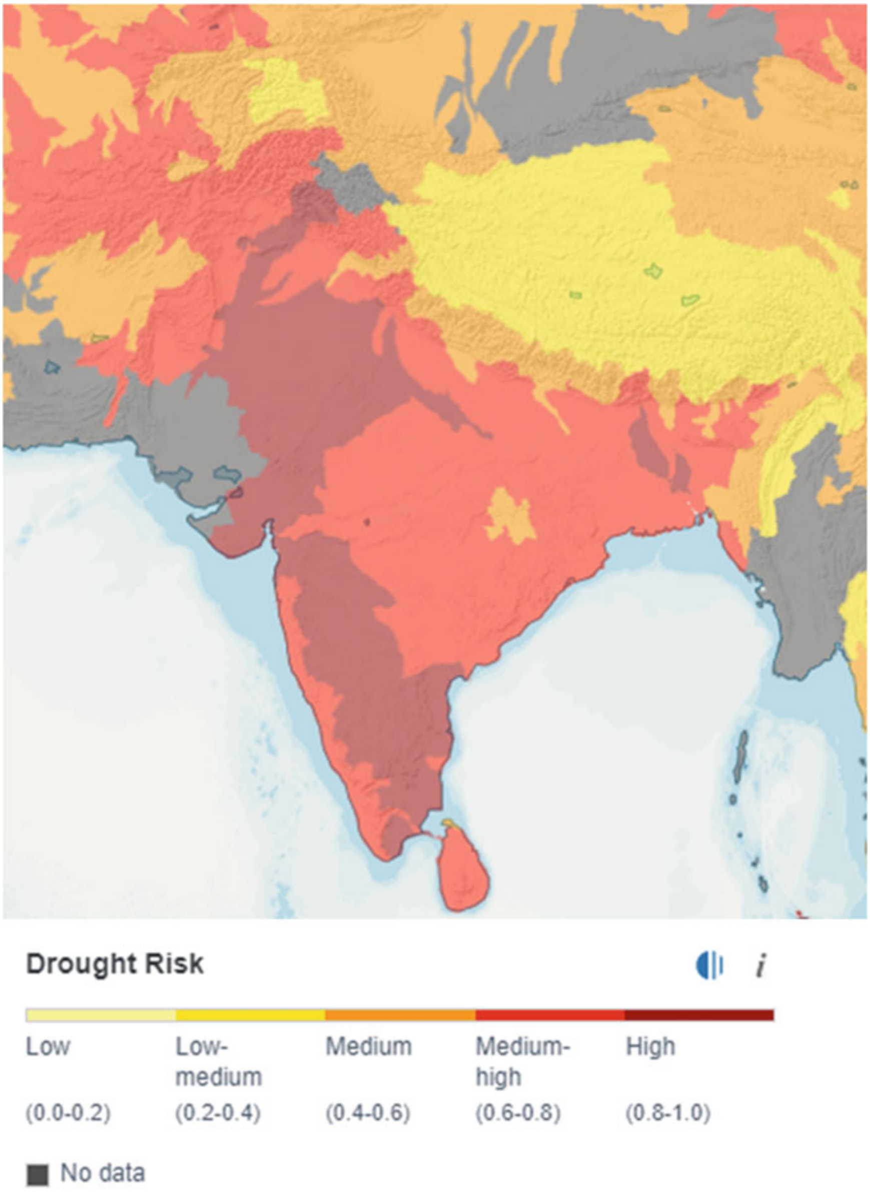

Fig. 8 Drought severity (Aqueduct Water Risk Atlas) for South Asia

impaired health, and destroyed infrastructure. It is important to integrate weather forecast, drought monitoring and early warning to develop near real-time agriculture drought contingencies to understand the monsoon behavior, agro-meteorology, farming systems in rainfed and hydrology for effective drought management.

Several countries in recent years have developed innovative drought management approach in the region from crisis response to risk management through early warning system, advance planning for emergency response and better preparedness for which satellite-based drought monitoring can guide government, NGOs and farmers in improving the agricultural production in both rainfed and irrigated areas for the sustainable management of drought prone areas. In this context it is important to develop short-term (5 years), medium-term (10 years) and long-term (20 years) for agriculture water management at multiple scale from on-farm to watershed and basin scale approach.

6 Summary and Conclusions

Remote sensing and GIS-based agricultural drought can be better monitored by multisource composite index such as IDSI composed of vegetation, precipitation, Evapotranspiration and soil moisture conditions. Drought-prone areas in South Asia are subject to increased drought frequency and impacting the rural population with growing demand on food and fodder among the marginal smallholder farmers.

Climate change leading to increase global temperature might lead to increased drought incidence in future. Mapping drought hotspots enhance agriculture water management and enable science-based policies for addressing water security in the agriculture sector. The future studies will relate areas of frequent extreme drought and precipitation events expected under climate change, alternatives to this scenario that improve water security could be achieved through careful pre- and post-drought planning and investment to maximize benefits from farm-level to watershed and basins.

To ensure food security it is important that decision makers support the management of ecosystem services by taking appropriate policy measures that promotes sustainable land management, integrated water resource management, climate smart farming practices in addressing the devastating impact on water security. Therefore, it is critically importantly to promote regional to basin and sub-national scale knowledge information on drought risk to address water security and promote proactive drought preparedness, mitigation and response strategies in the severely drought hit poor regions and vulnerable populations.

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Analysis of Flood Hazard in Kalutara District Using Geospatial Technology

A. K. Wickramasooriya and L. S. Walpita

Abstract People live in Kalutara district in Sri Lanka are suffering from flood situations in each year as floods are frequently experience in and around Kalu river (ganga). Thus flood hazard analysis in Kalutara district is an important step to be taken which will help in future to identify flood vulnerability, flood mitigation and planning human settlement in Kalutara district. In this study digital thematic maps are produced based on most causative factors influence to create floods such as distance from the drainage system (water buffer), elevation and land use. Different weightages introduced using pairwise comparison method and are calculated as distance from the drainage system, elevation and land use are 0.544, 0.346 and 0.11 respectively. As flood hazard varies with the variation of different conditions within a factor. Thus, using expertise knowledge different ranking systems are assigned for different conditions within each factor. Thereafter, flood hazard map of the Kalutara district had created using Multi Criteria Decision Analysis (MCDA) method based on weightages assigned for each factor and their ranks. According to this map, lands associated with flood hazard in the Kalutara district has classified as very high, high, moderate, low and very low which are 5.09%, 9.22%, 16.65%, 16.49% and 52.55%. The created flood hazard map has validated using flood inundation map introduced for the Kalutara district in 2003 and found that it has high level of accuracy and therefore, it can be utilized to flood related analysis in Abstract.

1 Introduction

It has been observing that due to floods there are many human lives as well as economic loses occur in each year. A flood is an overflow of water that submerges land, and may cause to damage agricultural lands, urban areas, and may even result in loss of lives (Rahmati, et al., 2015). Floods usually occur as a result of an extreme

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weather conditions and hydrological processes such as an intense precipitation, surface runoff and stream flows. Floods are natural disasters however, anthropogenic activities are also contribute to create floods. Urban areas with uncontrolled urban development, rapid population growth, an unregulated municipal system and an unplanned land use change in highly sensitive areas can be influenced to citrate floods cause devastating economic and social losses (Gigovic, et al., 2017). In Sri Lanka severe floods occurred from December to February (during Northeast monsoon) and May to September (during Southwest monsoon). Very severe floods in Sri Lanka occurred in 2003, 2011, 2012, 2016 and 2017. In 2003, 23 districts are experienced floods and 733,479 people were affected. During May 2017, 15 districts are experienced floods which leads to lost at least 208 human lives and misplaced 78 people (Wikipedia).

Hazard is the probability of occurrence of a potentially damaging phenomenon (Gabiña, 2013). A natural hazard is a threat of a naturally occurring event will have a negative effect on humans (Nelson, 2018). A hazard is perceived natural event which threatens both human lives and property while vulnerability is the extent to which a community's structure, services or environment is likely to be damaged or disrupted by the impact of a hazard (World Bank, 2017). Flood risk had assessed in the Western province in 2017 using statistical methods instead of geoinformatics techniques by Weerasinghe, et. al., in (2018). Asian Disaster Preparedness Center has identified the flood risk in the Kalutara district based on annual flood damage created for the district during 1983 to 2003 (ADCP, 2013). Department of Irrigation (2012) has introduced flood hazard map for Kalu river basin (sheet 73) considering previous flood events in and around Kalu ganga. However, this map has focused only for Kalu ganga basin. Also geoinformatics analysis has not been considered to create this flood hazard map. Therefore, the study under this paper focused to fulfil the research gap i.e. demarcation of flood hazardous areas in Kalutara district using Geoinformatics techniques as it is one of the main flood hazardous regions in Sri Lanka. This map can be utilized as a guide book to identify the suitable locations for implementing new development activities with minimal socioeconomic impacts experience due to future flood events experience in the Kalutara district.

1.1 Objective of the Research

The main objective of the research is to analysis and demarcate the most and least flood hazardous areas in the Kalutara district using updated information. Also the objective extends to minimize the social and environmental impact due to future lood events in Kalutara district as the created flood hazard map, will guide to recognize the areas which can be utilized for future development activities as well as human settlements without effect of floods.

1.1.1 Study Area

Kalutara district is situated in Western province of Sri Lanka. Average annual rainfall of the Kalutara district is about 2998 mm while an average annual temperature is about 26.9 °C. Kalu river is the main river in this district and is the main causative source for occur floods in this district. Kalutara district experience severe floods in 2003, 2011, 2016 and 2017. The Kalu river basin is about 2,803km^2. The annual discharge which is about 3 million cubic meters per square kilometer per year and is the highest in the country. This is because the upper catchment of the Kalu river is situated in the highest rainfall receiving region of the country (Wickramagamage, 2011). The Kalu river, which flows in a Northwestern direction, from Neboda, turns Southwest making a sharp bend and flows into the sea at Kalutara (Fig. 1). The position of this outfall varies annually and in some years even seasonally over a distance of several kilometers along the coastline.

1.2 Road Network and Settlements in the Study Area

Some of the roads, railways, houses and other buildings are located very closer to the Kalu river. Some of these can be affected by future flood events.

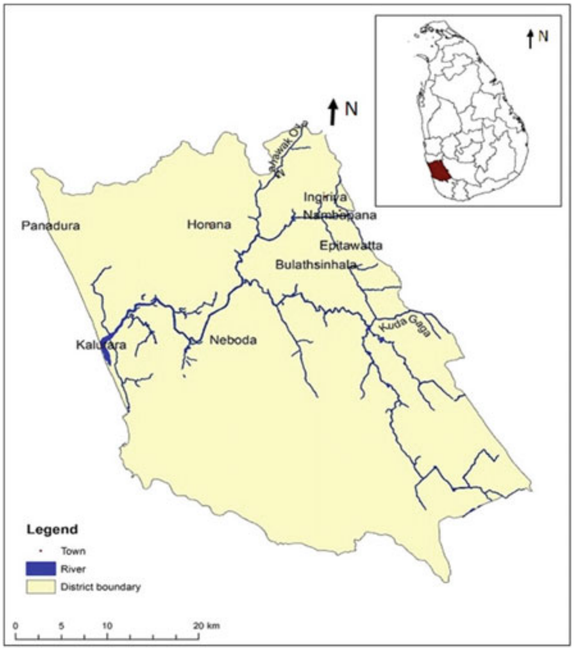

Fig. 1 Kalu river (ganga) in Kalutara district

1.2.1 Road Network

The road network in Kalutara district consist of Galle-Colombo main road, Southern highway express, railway tracks and many other roads are located within low elevated areas closer to the coastal zone in Kalutara district. Also it can be identified that few main roads and many minor roads are exist closer to the Kalu river.

1.2.2 Settlements

Distribution of human settlements are specially concentrated in and around the coastal zone and closer to the Kalu river. Further, many of them are situated at very low elevated areas.

2 Materials and Methods

2.1 Materials

Digital land use map (1:50,000 scale) of the study area created in 2015, secondary data such as dimensions of streams in the Kalutara district, discharge information, distribution of floodplain along the main river and its tributaries, past flood inundation areas (DMC, 2003), etc. are collected from the Department of Irrigation, Sri Lanka and the Disaster Management Center, Google images and Landsat images are utilized for this study.

2.2 Methods

This study mainly based on the integration of both applications of Geographical Information Systems and Multi-Criteria Decision Analysis (MCDA) method which is widely use in decision making analysis (Samanta, et al., 2016). The methodology of the research can be divided in to few main steps as shown in below as well as illustrated in the Fig. 2.

- Preparation of the database consist of digital thematic layers,
- Identify the main factors influence on flood hazard,
- Calculation of weightages for factors using pairwise comparison method,
- Assign ranks for different conditions within factors,
- Preparation of flood hazard map for the study area (using MCDA method and weighted overlay analysis method),
- Validation of created vulnerability map.

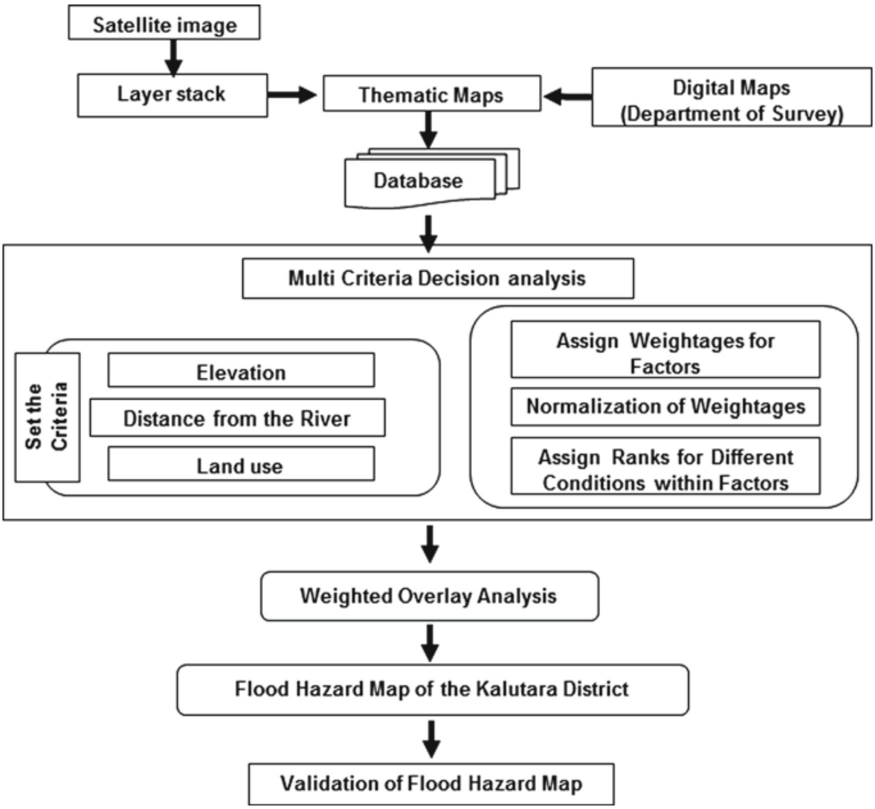

Fig. 2 Summary of the research methodology

2.2.1 Preparation of the Digital Thematic Database

Digital thematic maps are the main data sources needed in Geographical Information Systems applications. Therefore, some digital thematic layers like landuse, roads, contours, place names, etc. of 2015 are collected from the Survey Department of Sri Lanka. Some hard copy maps which are not available as digital data such as river buffer zones, past flood inundation maps, etc. are collected from the Irrigation Department of Sri Lanka and Disaster Management Center of Sri Lanka and these maps are converted in to digital thematic maps using ArcGIS software. All thematic layers are converted in to the same scale i.e. 1:50,000 and then georeferenced. Thereafter, these maps are converted into raster format and then relevant attribute data needed for the analysis of flood vulnerability in the study area are added to each attribute table of raster maps.

Table 1 Square pairwise comparison matrix of analyzing weightages

	Water buffer	Land use	Elevation
Water buffer	1	4	2
Land use	0.25	1	0.25
Elevation	0.50	4	1
Total	1.75	9	3.25

Source Based on method introduced by Bernard (2012)

2.2.2 Calculation of Weightages for Factors

Initially three main factors which can be involved for flood vulnerability in the area are considered. Those factors include, elevation from the Mean Sea Level (MSL), distance from the main river and its tributaries (water buffer) and land use types in the area. However, precipitation did not consider for the preparation of flood vulnerability map as it is considered as a triggering factor of creating flood and there is almost similar distribution pattern of precipitation can be observed for the entire study area. Also the discharge of the river indirectly represent the precipitation. The discharge of the river is considered when consider the distance away from the river or water buffer (floodplain). If not precipitation will be double counted for the analysis. After consulting the expertise in the Irrigation Department of Sri Lanka, factors influence on crating flood events are prioritized as water buffer or distance away from river and its tributaries, elevation and land use types respectively. Based on that criteria different weightages are calculated for each factor based on square pair-wise comparison method (using the spread sheet introduced by Bernard, SCB Associates Ltd., 2013) as shown in the Table 1.

2.2.3 Calculate Normalized Weightage Values

These weightages are converted into normalized values to increase the accuracy of the analysis (Table 2).

C1 - Water Buffer.
C2 - Land use.
C3 - Elevation.

Table 2 Normalized Matrix

	C1	C2	C3	Weightage
C1	0.571	0.444	0.615	0.544
C2	0.142	0.111	0.077	0.110
C3	0.285	0.444	0.308	0.346
Total	1	1	1	1

Source Based on method introduced by Bernard (2012)

According to Analytical Hierarchy Process analysis, weightages assigned for distance from the river (water buffer), elevation and land use are 0.544, 0.346 and 0.110 respectively. The row average provides an approximation of the eigenvector of the square reciprocal matrix. The eigenvector is an estimate of the relative weights of the criteria been compared. Because individual judgment will never agree perfectly the degree of consistency achieved in the ratings is measured by a Consistency Ratio (CR) indicating the probability that the matrix ratings were randomly generated. The rule of thumb is that a CR less than or equal to 0.1 indicates an acceptable reciprocal matrix while the ratio over 0.1 indicates that the matrix should be revised. Revising the matrix entails, finding inconsistent judgments regarding to the importance of criteria, revising these judgments by comparing again the pairs of criteria judged inconsistently.

2.3 Calculate Consistency Ratio (CR)

The Consistency Ratio can be calculated using the following equation.

$$CR = CI/RI \tag{1}$$

where, CR - Consistency Ratio, CI - Consistency index.

$$CI = (\lambda_{max} - n)/(n - 1) \tag{2}$$

λ_{max} Principal Eigen Value.
n Number of criteria.
RI The Random Consistency Index.

RI can be obtained using the standard values given in the Table 3.

In this analysis there are 3 indices (n = 3) for matrix and therefore, RI = 0.58.Thus, CI for the analysis can be calculated as shown in below:

$$\begin{aligned} CI &= (\lambda_{max} - n)/(n - 1) \\ CI &= 0.0342898 \end{aligned} \tag{3}$$

$$\begin{aligned} CI &= 0.0342898 \\ CR &= CI/RI \end{aligned}$$

Table 3 Random Indices for matrices of various sizes

n	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
RI	0	0	0.58	0.9	1.12	1.24	1.32	1.41	1.45	1.51	1.52	1.54	1.56	1.58	1.59

Source Estoque, (2011), GIS based MCDA, (n - no of indices in the matrix)

$$= 0.05912032 \quad (4)$$

The value of CR = 0.05912 falls much below the threshold value of 0.1 and it indicates a high level of consistency. Hence calculated weightages for three factors can be accepted and those weightages can assign for the analysis of flood vulnerability in the study area.

2.3.1 Assign Ranks for Different Conditions Within Factors

Different conditions within a factor may influence to create floods in different manner. For example, areas closer to the river may have higher flood vulnerable than areas located far away from the river. Therefore, high vulnerable areas should assign higher ranks than the other areas. Similarly the other two factors considered to analyze flood vulnerability, conditions within those two factors to be considered. Therefore, different ranking systems for three factors introduced based on effect on different conditions within each factor. However, to assign ranks there should be an accepted criteria. After consultant the irrigation engineers at the Department of Irrigation and expertise in the Disaster Management Center different relative ranking systems introduced for each factor. To complete this task, Staaty's (1988) 1 to 9 relative scale which is widely used to determine the relative importance of factors and fuzzy pair-wise comparison methods have used (Table 4). Relative ranks introduced for three factors are given in Tables 5, 6 and 7. However, all relative importance scales from 1 to 9 are not included for the analysis. Missing scales within factors implies that those conditions of factors not exist within the study area or those scales are not effect for the analysis. Therefore, some of the relative ranks have combined. Thus ranks of 7, 5, 4 and 3 of distance from the drainage network, ranks of 8, 6, 2 and 1 of land use and ranks of 8, 6, 5, 3 and 1 of elevation did not consider for the analysis and as the conditions effect for the analysis are very similar to some other conditions, these ranks are combined with the ranks of conditions which are behave in similar manner.

Table 4 Staaty's scale of relative importance (1988)

Scale	Numerical rating	Scale	Numerical rating
Extremal preferred	9	Moderately to strongly	4
Very strong to extremely	8	Moderately preferred	3
Very strongly preferred	7	Equally to moderately	2
Strongly to very strongly	6	Equally preferred	1
Strongly preferred	5		

Table 5 Distance from the drainage network

Class	Distance from the river (m)	Rank
1	<100	9
2	100–200	8
3	200–500	6
4	500–1000	2
5	>1000	1

Table 6 Land use type

Class	Land use type	Rank
1	Water	9
2	Paddy	7
3	Home Garden	5
4	Tea	4
5	Coconut, Rubber	3

Table 7 Elevation

Class	Elevation (m)	Rank
1	<10	9
2	10–20	7
3	20–50	4
4	>50	2

2.3.2 Preparation of Flood Vulnerability Map

Flood vulnerability map for the study area has introduced using Multi Criteria Decision Analysis (MCDA). Multi Criteria Decision Analysis method is one of the best analysis techniques which is used to analyze digital maps for decision making (Estoque, 2011), By overlay of weighted pixels of all factors Flood Vulnerability Index (FVI) has introduced. This index is calculated as percentiles using the following equation and it will be a value between1.00 and 9.00. In here both fuzzy overly and weighted overlay methods used to introduce the flood vulnerability map for the study area (Sangrawee, et. al, 2007).

$$\mathrm{FVI} = \sum \mathrm{W_i R_j}$$
$$\mathrm{FVI} = \mathrm{W_1} * \mathrm{R_j} + \mathrm{W_2} * \mathrm{R_j} + \mathrm{W_3} * \mathrm{R_j} \quad (5)$$

FVI—Flood Vulnerability Index, $\sum$ - Summation, I - No of factors, J - Appropriate rank of the factor, W - Weightage assigned for factor, R - Rank assigned for conditions within a factor (from 1 to 9).

Based on the above procedure main three factors considered in this study i.e. distance to the river or water buffer, elevation and land use types with their relative weightages and ranks considered to produce the flood vulnerability map of the Kalutara district. This process is discuss in detail in the results chapter.

2.3.3 Validation of Created Vulnerability Map

In general practice digital maps produce using applications of Geographical Information Systems to be validated to check their accuracy. Therefore, the flood hazard map which was produced using weighted overlay method and Multi Criteria Decision Analysis Method has to be validated to assess the accuracy of the map. Otherwise the created map cannot be accepted. Therefore, the created flood vulnerability map has compared with flood inundation maps introduced by the Disaster Management Center in 2003 and 2017 for validation.

3 Results

The initial step of the study was create the digital thematic maps from the hard copy maps collected from various institutes. Three main factors consider in this study are distance from the Kalu river and its tributaries (water buffer) and its tributaries, elevation of different locations of the study area and the land use type distribution of the study area. The relevant hard copy maps are collected and converted in to digital thematic layers using ArcGIS software. Also few attribute data are added to attribute tables of these thematic layers.

3.1 Preparation of Ranked Water Buffer Thematic Layer

Based on the distance from the river and its tributaries, water buffer zones are divided into five classes i.e. less than 100 m, within 100–200 m, within 200–500 m, within 500–1000 m and greater than 1000 m (Table 4). The ranked water buffer thematic layer which was prepared considering these categories is shown in Fig. 3a. The area within 100 m, 100 m to 200 m, 200 m to 500 m, 500 m to 1000 m and greater than 1000 m are 3.66%, 3.46%, 9.53%, 13.36% and 69.99% respectively. Therefore, according to the distance away from the Kalu river and its tributaries (water buffer), only small area can be considered as high flood hazardous areas.

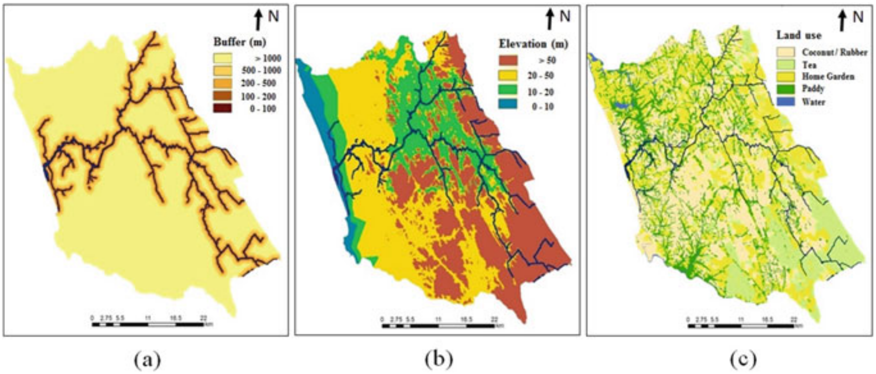

Fig. 3 **a** Distribution of water buffer classes in the Kalutara district, **b** Distribution of elevation classes in the Kalutara district and **c** Distribution of land use classes in the Kalutara district

3.2 Preparation of the Ranked Elevation Thematic Layer

The elevation in the study area divided in to four classes i.e. less than 10 m, between 10 and 20 m, between 20 and 50 m and greater than 50 m (Table 6). The ranked elevation thematic layer has been created considering these classes as well as their ranks are shown in Fig. 3b. According to this map, high elevated lands i.e. greater than 50 m above M.S.L is about 34.87% out of the total area which are distributed in Southeastern and Eastern part of the study area. About 40.78%, 20.04% and 4.31% out of the total area of the Kalutara district are within 20 m to 50 m, within 20 m to 10 m and less than 10 m above M.S.L respectively. Therefore, when consider the elevation factor, only a small area specially along the coastal zone can be identified as at high flood hazardous area.

3.2.1 Preparation of Ranked Land Use Thematic Layer

Digital maps of Survey Department as well as Landsat satellite images of 2016 are utilized to create land use thematic layer. At first, using digital maps collected from the Survey Department, existing information on those maps are modified and updated using satellite images. Thereafter, land use types in the Kalutara district have classified in to five classes according to the criteria introduced (Table 5) to analyze the flood hazard. The ranked land use thematic layer which is shown in the Fig. 3c is created considering the above classification and corresponding ranks. Majority of coastal lands are coconut lands. According to this map out of total area of the Kalutara district, Coconut and Rubber lands, Home gardens, paddy lands and tea lands are about 38.58%, 29.03%, 16.82% and 13.47% respectively.

According to the distribution pattern of the land use types in the study area, paddy lands which are mainly exist at low elevated areas and closer to the Kalu river and its tributaries which are more hazardous than the tea lands which are exist at high elevated lands.

4 Discussion

As explained in the methodology chapter, using ranked maps produced in the above; the flood hazard map of the Kalutara district has been introduced as explain in the below. Also created flood hazard has utilized to analyze the flood vulnerability in the Kalutara district specially considering the road network and the settlement of the area.

4.1 *Preparation of Flood Hazard Map*

As mentioned in the methodology, according to the expertise in the Disaster Management Center and the Department of Irrigation, three most important causative factors for flood hazard mapping i.e. distance from the main river and its tributaries, elevation from the MSL and the distribution of land use types in the Kalutara district are considered to create the flood hazard map for the Kalutara district. Based on the weightages introduced using pairwise comparison method as described in the methodology chapter i.e. distance from the river (water buffer), elevation and land use are 0.544, 0.346 and 0.110 respectively and ranking systems introduced for each factor, flood hazard map for the study area has introduced as shown in Fig. 4 using weighted overlay analysis technique available in the ArcGIS software.

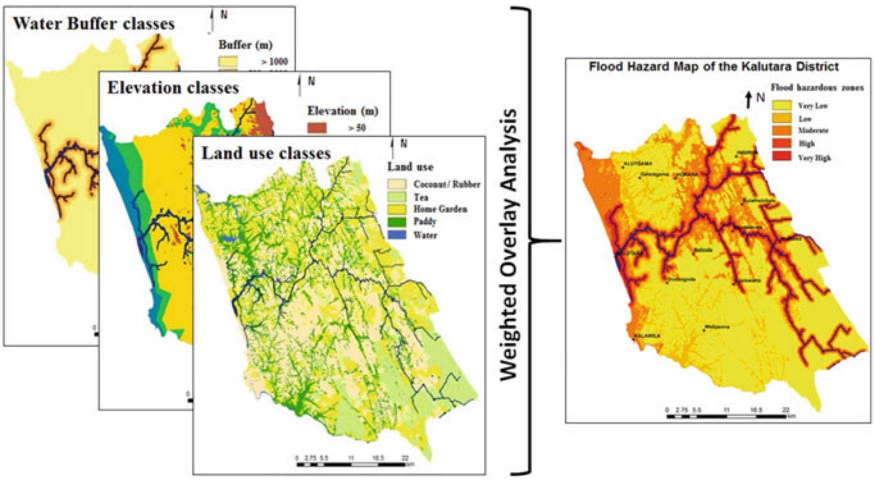

Fig. 4 Preparation of the flood hazard map using weighted overlay analysis method

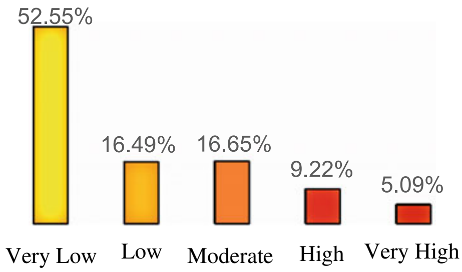

Fig. 5 Flood hazard in the study as percentages

In this map flood hazardous areas in the Kalutara district has classified into lands with very high, high, moderate, low and very low. It has been observed that very high flood hazardous areas are associated in either sides of Kalu river and its tributaries. Also paddy lands which are at relatively flat and low elevated areas as well as flat coastal plain closer to Kalu river can be identified as high flood hazardous lands. According to the created flood hazard map of the Kalutara district, mainly low and moderately low flood hazardous areas can be identified in the Southwestern and Northwestern parts which are situated far away from the main river and its tributaries and is the main reason that these lands have low flood hazard. The main city in the Kalutara district i.e. Kalutra is located within the very high to high flood hazardous zone. Based on the flood hazard map it can be found that land areas having very low hazardous, low hazardous, moderate hazardous, high hazardous and very high hazardous compared to the total extend of the Kalutara district are 52.55%, 16.49%, 16.65%, 9.22% and 5.09% respectively (Fig. 5). According to these percentages, it was noted that about 70% of the study area are belongs to very low or low flood hazardous areas.

4.2 *Validation of the Flood Hazard Map*

Validation of digital thematic layers created using Geographical Information Systems or Geoinformatics techniques is one of the most important task to be followed. As these maps are created using available hard copy maps, digital maps and other attribute data, the final outcome to be represented the real environmental conditions and socioeconomic status of the region. Therefore, without validation of maps created using GIS techniques, there is no reliability of these maps. Field truth verification and comparison of created maps with past evidences two methods which can be implemented for the validation process. However, in this study it is possible to validate the introduced flood hazard map using field truth verification as there aren't any evidences of floods currently available. Therefore, the second method i.e. utilize past flood information, satellite images and flood hazard maps created by various institutes using different criteria other than geoinformatics methodologies are utilized to validate the created flood hazard map. Flood situation occurred in 2003 and which was severely affected in the Kalutara district, satellite imageries of the study area when there were sever flood events occurred in the past and other past flood information are considered to validation process.

4.2.1 Validation of the Created Flood Hazard Map Using 2003 and 2017 Flood Situations

The Disaster Management Center (DMC) of Sri Lanka in collaboration with the Department of Irrigation has analyzed the 2003 flood situation and introduced flood inundation map based on surface runoff distribution pattern due to flood for Kalutara district (DMC, 2003). Four severely flood affected areas demarcated in this map i.e. Kalutara, Ingiriya, Dodangoda and Bulathsinhala (Fig. 6a–d) are considered to validate the flood hazard map developed in this study. The flood hazard map has been introduced using 2015 topographic maps, recent satellite images and other updated information. Flood inundation maps of DMC are digitized and georeferenced. Thereafter these inundation maps and created flood hazard maps are overplayed and compared different flood situation using 2003 and 2017 flood inundation maps of DMC. It was noted that most flood inundation areas marked in 2003 DMC flood inundation map are associated the very high and high flood hazardous areas in the created flood hazard map (Fig. 6).

According to this validation process it was found that nearly 88 to 92% of the very high to high flood hazardous areas in the introduced flood hazard map of the above four regions are within the flood inundation areas demarcated in both 2003

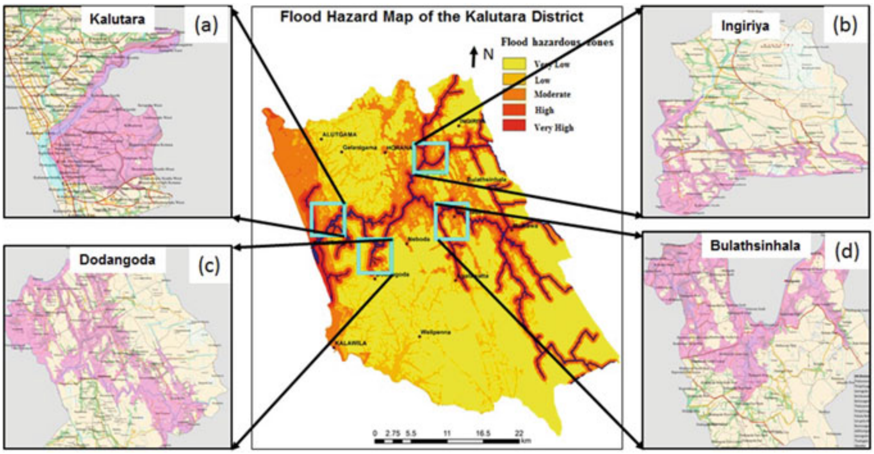

Fig. 6 Validation of created Flood Hazard Map using Flood Inundation map introduced for the Kalutara district in 2003 by the Disaster Management Center, Sri Lanka

and 2017 flood inundation maps introduced by DMC. Also about 85% to 90% of the very low and low hazardous areas in the flood hazard map are located within ssflood unaffected areas in flood inundation maps introduced by the DMC in 2003 and 2017. Therefore, the produced flood hazard map has high level of accuracy.

4.2.2 Comparison Between Flood Hazard Map and Satellite Imagery Data During Flood Situations in the Area

Areas marked as very low hazardous, low hazardous, moderate hazardous, high hazardous and very high hazardous are compared with google images and Landsat images when there was an extensive flood occurred during 2017 in Kalutara district. After analyze the created landslide hazard map and these images it was found that almost all areas marked as high hazardous and very high hazardous areas are lies within flood inundated areas in satellite images which is an indication of the high accuracy of the created flood hazard map.

5 Conclusions

Flood is one of the main natural hazards experience in Kalutara district specially the areas associated with Kalu river (ganga). Therefore, it is very essential to identify high flood hazardous areas in Kalutara district. In this study flood hazard map for the Kalutara district has created using most updated informant and considering most important causative factors of creating floods which are recommended by the DMC and the Department of Irrigation. These factors include distance from the drainage network, elevation and existing land use types in the study area. Rainfall can be considered as a flood triggering factor. However, rainfall is indirectly considered in water buffer (rain water added to the river as stream flow and surface runoff). Therefore, rainfall is not considered as a main factor when analyzing flood hazard in this study. The relative weightages for each factor has assigned based on pairwise comparison method. Weightages calculated for distance from the river (water buffer), elevation and land use are 0.544, 0.346 and 0.110 respectively. To analyze whether these weightage values are reliable, Consistency Ratioo (CR) had calculated using standard formula and it is calculated as 0.05912 which is much below the threshold value i.e. 0.1 indicating that the weightage values assigned for each factor has high level of consistency. As flood hazard can be varied with the variation of different condition within a factor, each factor has classified into classes and assigned ranks for each class based on pair-wise comparison method. Thereafter, using the assigned weightages for factors and ranks assigned for different classes within each factor, flood hazard map of the Kalutara district has been created using Multi Criteria Decision Analysis (MCDA) and Weighted Overlay methods. This map has validated using flood inundation maps introduced by the DMC in 2003 and 2017. Also the created hazard map has compared with the flood situation in 2017 in the area using satellite images. Based on this validation process it was confirmed that the created flood hazard map can be accepted with a high level of accuracy. According to the introduced flood hazard map of the Kalutara district, lands with very high hazardous, high hazardous, moderate hazardous, low hazardous and very low hazardous are 5.09%, 9.22%, 16.65%, 16.49% and 52.55% out of total study area respectively. This map can be utilized to flood related analysis such as flood vulnerability and flood risk in the Kalutara district. Therefore, the created map is very useful to select and establish future development activities and human settlements in Kalutara district with minimum flood hazards and flood risks.

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A Preparedness Index (PI) to Assess the Capacities for Tsunami Warning and Evacuation Planning: A Case Study from Padang City, Indonesia

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Abstract Tsunami is a hydrological hazard that has attracted a significant attention in the disaster risk reduction (DRR) discipline since the phenomena of unprecedented coastal urbanization has been increasing the causes for tsunami risk in coastal cities. Padang is the capital city of the West Sumatra in Indonesia and a coastal city frequently affected by tsunami impacts triggered in the 'Pacific ring of fire'. Hence, the tsunami warning and evacuation planning is considered as a critical need in the DRR strategies of the Padang city. This research is aimed at evaluating the relevant capacities within the Padang city for improving the preparedness for tsunami hazard. The overall preparedness of the city for potential tsunami impacts has been assessed by calculating the preparedness index (PI) which is composed of four key indicators; Knowledge and attitudes (KAP), emergency response plan (EP), early warning system (WS), mobilization of resources (RM). The results recorded 74/100 for PI which categorizes the city as 'ready for preparedness' signifying the availability of high capacities for the improvement of tsunami warning and evacuation planning. The result of the PI can be further interpreted to identify the structural measures such as vertical shelters and evacuation routes for the better preparedness against tsunami hazard.

Keywords Disaster risk reduction · Padang city · Preparedness index · Tsunami evacuation

1 Introduction

The disaster risk of natural hazards has become more escalated as the number of extreme weather events and the threat of earthquakes is risen with the effect of climate change (UNDRR, 2019). According to the disaster records of IFRC (2018) during the past decade since 2017 the Asian continent has been affected by the highest

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number of natural disasters compared to other continents. Within the Asian continent, Indonesia, which consists of more than 18,000 islands and hosts 224 million population has been identified as a highly vulnerable country for earthquakes and tsunami hazards (ESCAP, 2019). During the past 20 years, Indonesia has experienced more than 14,000 earthquakes with more than 5.0 Mw magnitude, where the largest is 2004 Aceh earthquake and tsunami with a magnitude of 9.2 Mw (Gempa, 2010; World bank, 2019). Among the cities in Indonesia, the international research communities have identified Padang as the highest vulnerable city for earthquakes and tsunami hazards due to its geographical exposure for tsunami waves and the rate of urbanization along the coastal boarder (McCloskey et al., 2008; Rahayu et al., 2020; Taubenböck et al., 2009). Considering the increasing threat of earthquakes and subsequent tsunami hazards (Singh et al., 2010), the Padang local government together with national Disaster Risk Management (DRM) plans, has initiated various efforts to develop Early Warning Systems (EWS) and evacuation plans. However, the lack of governing capacities for effective Disaster Risk Reduction (DRR) and DRM plans, the Padang city remains with evacuation capacity needs for another 92.36% of its vulnerable population (Ashar et al., 2014). Therefore, the Padang city needs a comprehensive intervention with a vertical evacuation plan supported by community-based disaster preparedness for effective preparedness for tsunami hazard. This research was carried out with the aim of evaluating the tsunami evacuation planning process in Padang city, to develop a Tsunami Preparedness Index in support of the tsunami evacuation planning.

2 Tsunami Hazard and Preparedness for Disaster Risk Reduction

A disaster is a serious disruption of the functioning of a community or a society at any scale due to hazardous events interacting with conditions of exposure, vulnerability and capacity, leading to one or more of the following: human, material, economic and environmental losses and impacts (UNISDR, 2016). Earthquakes and tsunami belong to the hydrological/geophysical group, caused by the events originating from earth. The tsunami risk assessment includes a thorough knowledge of the exposure to hazard, vulnerability, and level of preparedness (UNESCO/IOC, 2017).

The exposure to an earthquake or a tsunami hazard is directly depending on the distance from the source (earthquake, landslide, volcanic eruption) to the vulnerable elements (Di Mauro et al., 2013). Vulnerability assessment covers the distribution of population, buildings, infrastructure, and other critical assets which are likely to be affected by a tsunami (Atillah et al., 2011). The primary tasks in the procedure for increasing preparedness for tsunami hazards includes the identification of an appropriate early warning framework and raising awareness of the risk at all levels in the community (Haigh et al., 2020). The DRM plan indicates the key operational requirements of an early warning system, preparing all community levels for emergency response and evacuation, and promotes Community-Based Disaster Risk Management (CBDRM) (UNESCO/IOC, 2014).

In this context of risk assessment, the profession of risk management contain an essential role to formulate effective preparedness policies, which consists the information for response and evacuation, including local hazard maps, vulnerable and safe zones, evacuation routes and signs, evacuation shelters, awareness and education, and communication mechanisms.

Sutton and Tierney (2006) have identified several integral elements for an effective disaster preparedness policy. Those include knowledgeable about the hazard (risk, vulnerability), relevant policies and guidelines to preparedness, plan for emergencies situation, disaster warning system, and the ability to mobilize resources. Simpson (2008) proposed an inductive approach to assess disaster preparedness by evaluating the appropriateness of ten indicators. These indicators are comprised into four parameters in the preparedness explanation by LIPI and UNESCO (Hidayati et al., 2006); namely Knowledge and Attitude (KA), Emergency Planning (EP), Warning System (WS) and the mobilization of resources (RM). The Indonesian Institute of Science in cooperation with UNCESCO/ISDR has synthesized these parameters into an evaluative mechanism and developed a disaster preparedness framework to evaluate the level of preparedness of communities for earthquake and tsunami risks in Indonesia (Spahn et al., 2014).

3 Tsunami Hazard and Disaster Risk in Indonesia and Padang City

The Padang city is the third largest city on the island of Sumatra, approximately hosts 800,000 inhabitants. In 2016 Padang is estimated to be 95.8% urban in total metro area population and Padang is the most congested city in the East Asia and Pacific region (Roberts & Sander, 2019). It is categorized in the 1–5 million metropolitan agglomeration group which anticipates a 5 million growth in its population (World-Bank, 2012). An average of 5–10 km coastal boarder towards the Padang city consists 0–2% elevation in topography which makes 24% of the total city extent vulnerable for a tsunami impact. According to the BNPB (2016) 84% of the total fatalities during the last 2 decades are recorded as the causes of earthquakes. Padang City is ranked as the 10th nationality in the high hazard category of world disaster risk index (BNPB, 2016).

The source event that could create a tsunami in Sumatra is the Sunda-arc subduction zones, both submarine features which can generate a significant megathrust earthquakes and potential tsunami waves (UNESCO/IOC, 2017). Padang city is located close to the subduction zone where the city can face Near-field tsunami impact within 20–30 min from the occurrence of the earthquake (Fig. 1) (Singh et al., 2010). Out of the many earthquakes and tsunami events in Sunda-arc subduction zone the Aceh-Andaman earthquake in 2004 (Mw 9.15) caused the highest

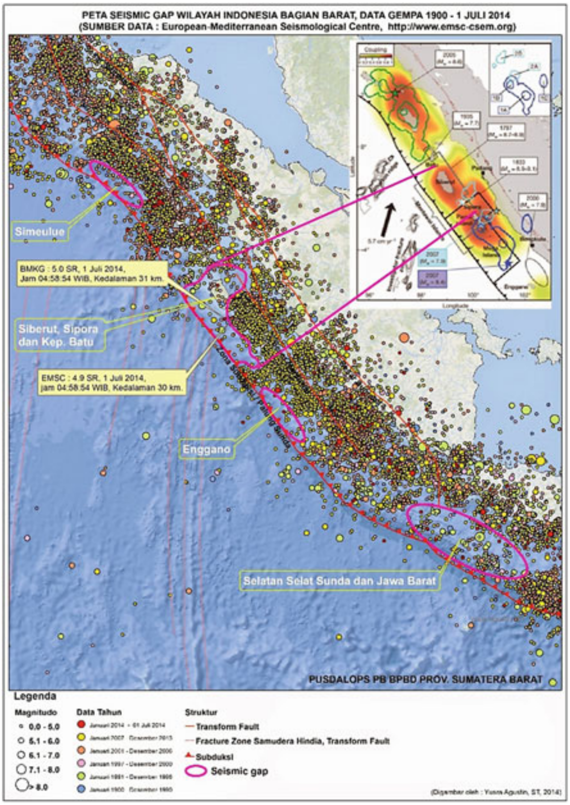

Fig. 1 Seismic gap map of west region Indonesia, earthquake recorded from 1900–2014. *Source* European-Mediterranean Seismological Centre

damage to Padang (Muhammad et al., 2016) and raised the significance of Tsunami Evacuation Plan (TEP) as a primary concern of all stakeholders in Padang City.

The primary aim of a TEP is to guide all vulnerable communities towards the safe places via evacuation routes, and most of these are established by local decision makers (Scheer et al., 2012). Singh et al., (2010) explain that the Padang city needs a comprehensive TEP that has the capacity to warn and evacuate approximately 400,000 of vulnerable communities to safe locations within a range of 5 km in 10–15 min. Amongst the growing exposure to tsunami hazard, the city has been preparing over various mapping and risk assessment measures. However, the city remains with a significant gap for integrating the TEP with national development policies and local preparedness and community engagement.

4 Present Evacuation Planning Approaches in Padang

The handbook of TEP—SCHEMA (Scenarios for Hazard-induced Emergencies Management) has identified three phases for evacuation planning; preparing the evacuation plan, mid-term and long-term revision, and integration (Scheer et al., 2012). Further, The SCHEMA has identified several constraints in compiling TEP, including absence of early warning analysis tools, shelter sites, community engagement, decision makers' interest, evacuation of population with special needs, and tsunami warning limitations. The GITEWS project has identified two key components for the TEP process: 1. tsunami evacuation maps and 2. evacuation strategies which provides tsunami risk specific local strategies for different vulnerable zones (GITEWS, 2010a, b).

SCHEMA uses more scientific data or calculations such as bathymetry data, or tsunami modelling while GITEWS engages more communities and stakeholders in the TEP process.

Based on these literature findings, this study conducted an evaluation in the key parameters of the three models (Scheer et al., 2012; Spahn et al., 2010; UNESCO/IOC, 2017) to identify an appropriate disaster preparedness index for tsunami hazard in Indonesian context. Both scientific simulation and community engagement are conveniently utilized in the index development to overcome the limitations identified in the literature.

5 Research Aims and Objectives

The aim of the research is to evaluate the Tsunami Evacuation Planning process in Padang City, to develop a Tsunami Preparedness Index in support of the tsunami evacuation planning. Research objectives are identified as mentioned below.

- To explore the applicability of present TEP processes in Padang.
- To identify valid indicators for evaluating the tsunami preparedness by exploring the tsunami characteristics in Padang.
- To evaluate the level of tsunami preparedness of Padang city government and communities by exploring the available TEP and planning process.
- To recommend suitable solutions for the TEP process of Padang to overcome the existing constraints and harness the available potentials.

Further, the research intends to identify the level of preparedness of the government and community and analyze the strengths and constraints to recommend with suitable evacuation planning solutions. Accordingly, the following aspects are explored in detail.

1. The characteristics and impact of tsunami hazard in the city of Padang.
2. The existing challenges to implement an integrated TEP in Padang.

3. The role of government and communities in TEP process.
4. The present state of capacities of government and community for TEP in Padang.
5. The potential solutions to improve the TEP process in Padang.

6 Methodology for Data Collection

The research process is consisted of an extensive survey of government and community stakeholders who are involved in the TEP process and implementation. The research is guided by the onion research model (Saunders et al., 2015) emphasizing the interpretivism philosophy for an inductive approach. The case study is carried out in the Padang city of Indonesia focusing the tsunami evacuation planning process as the single unit of analysis. Mixed methods are used in data analysis, supported by the data collection through documents, archival records, interviews, and direct observation (Yin, 2014).

Respondents for the data collection were identified from the resident population who are living in the tsunami prone areas in the Padang city and the policy decision makers, relevant government, community, and NGO officials were interviewed using a structured questionnaire. The distribution of the resident respondents was recorded as mentioned in the Fig. 2. Out of the total 257 respondents, 214 are in the red zone, which is prone to tsunami impact, and 43 are in the tsunami safe zone, which is out of the tsunami direct impact (Strunz et al., 2011).

7 Research Findings and Conceptual Framework for Developing the Tsunami Preparedness Index

The main tasks identified in the process for developing a tsunami preparedness index can be concluded to the following steps.

1. Identifying the framework of appropriate early warnings to increase the risk awareness at all levels of society,
2. Planning and implementing key operational requirements of an early warning system,
3. Setting up all walks of life for emergency response,
4. Developing planning systems and evacuation procedures, and
5. Promoting Communities based Disaster Risk Management (CBDRM) where appropriate.

The following indicators which were identified in the literature synthesis were used to evaluate the preparedness in the city of Padang for tsunami risk. (1) the knowledge and attitudes (KA), (2) an emergency response plan (EP), (3) early warning

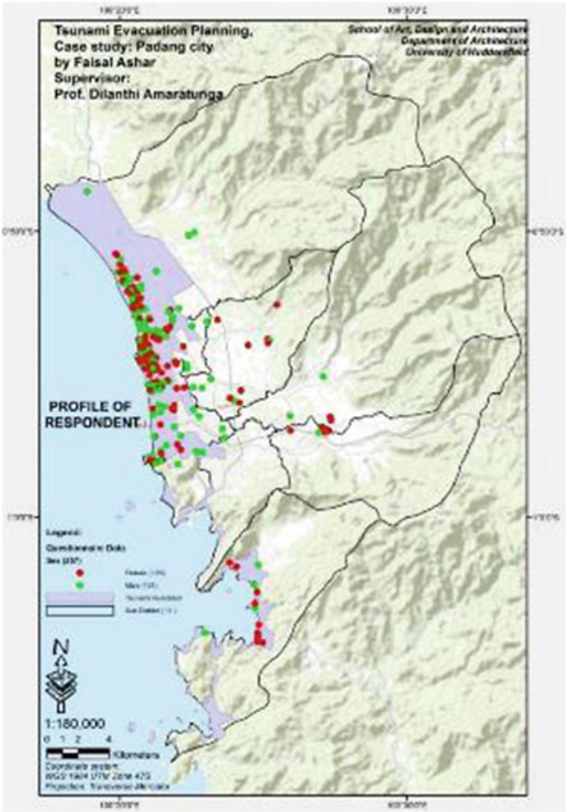

Fig. 2 GPS locations of respondents

system (WS), and (4) mobilization of resources (RM). The first parameter; KA was used to measure the basic knowledge about natural disasters (characteristics, signs, and causes). The EP identified the activities which are already adapted for natural disasters. WS as the third parameter, measured the availability of warning signs, communications, and mechanisms within community to prevent disaster impacts. The last parameter was the RM, which indicated the availability of resources in the community (workshops, financing, and other equipment) (Hidayati et al., 2006; IOC/UNESCO, 2015).

The index is proposed to support the capacity evaluation in both government and community.

- The capacity evaluation of the government will be important to measure the level of preparedness and to take actions in evacuation planning and implementing.
- The capacity evaluation of the community will be important to understand their ability to perform self-evacuation and the response to evacuation plans.

7.1 State of Preparedness in the City of Padang for Tsunami Risk

7.1.1 KAP—Knowledge and Attitudes

The KAP is measured using several variables to understand the respondents' perspectives on the characteristics of the earthquakes and occurrence of tsunami, tsunami resilient housing constructions, and preparedness and response measures against an earthquake or a tsunami risk. 99.6% of the respondents are aware that after an earthquake, a potential tsunami incident is indicated by the receding water level in the sea. Moreover, 64% of respondents from both zones (red and safe) agree that a tsunami can potentially occur even without being preceded by water receding. However, only 32% of the respondents have a clear idea on the tsunami estimated time of arrival (ETA) from its origin to the coast of Padang. Even though occurrence of an earthquake has not been able to forecast accurately, the 92% of the respondents are aware of the importance of being prepared for such occurrence and response timely to evacuate to safe locations.

7.1.2 EP—Emergency Planning

The emergency response plan serves as one of the crucial elements in the process of preparedness, especially when it relates to the evacuation, relief, and rescue to minimize disaster victims (UNISDR, 2006). 67% of the respondents have learnt positive lessons from the previous evacuation incidents. Even though, the attitude towards tsunami preparedness is positive in 97% of the respondents, the awareness on preparedness and response measures are available with only 29%. Only 31% of the respondents are adapting tsunami resilience practices in the housing construction and the participation in evacuation simulation drills are recorded only within 23%. Only 19% is aware about the use of an evacuation map and 29% are convinced about the use of a tsunami shelter. Overall, 56% are prepared with a standby backpack and 70% keep a copy of the important documents saved, yet the evacuation mechanisms should be strongly conveyed to the community.

7.1.3 WS—Warning System

Early warning system and peoples' response to the warning messages and signs are important indicators of measuring community preparedness for tsunami risks. Out of the total respondents 53% mentioned the adequate clarity of the warning communication mechanisms. Community have identified dedicated sirens, media information and loudspeakers in community buildings as effective communication mechanisms for tsunami early warning.

7.1.4 RM—Resources Mobilization

Availability of resources that can be mobilized in emergency conditions is an important indicator of community preparedness for tsunami risk. According to the survey result, the availability of community evacuations plans (9%) and participation in the tsunami awareness workshops (32%) are very minimal in the Padang city. Even though, the Padang government has established 114 community-based disaster preparedness (KSB) groups, only 50% of the respondents had close interaction with them.

7.1.5 PI—Preparedness Index

The level of community preparedness in this study is reflected through the categories (KAP, EP, WS, and RM) synthesized by Hidayati et al. (2006) which are grouped into five using the Eq. (1). The weight of each parameter is identified from the responses to the questionnaire survey.

$$\text{Index} = \{\text{Total score of each parameter}/\text{Maximum score of the parameter}\} \times 100 \quad (1)$$

Using the 257 responses, the weights for each parameter were calculated using liner regression analysis tools of SPSS. The weights of each parameter for individual and household index (%) are KAP (0.30), EP (0.53), WS (0.05), and RM (0.12) in which the preparedness Index (PI) (Eq. 2) is the total of the weight multiplied from the indices for each parameter (Table 1).

$$\text{Preparedness Index(PI)} = 0.30 * \text{KAP} + 0.53 * \text{EP} + 0.05 * \text{WS} + 0.12 * \text{RM} \quad (2)$$

According to the survey result (Table 2), Padang City PI for individuals/households scored 74 and categorized as ‘Ready for preparedness’ for tsunami evacuation and response as indicated in the Table 1. The index of individual preparedness seen from each parameter indicates that the highest value is KAP (77) and the lowest is WS (69). Other indices record moderate high values from the analysis, EP (73) and RM (70).

Table 1 Category of community preparedness

No	Index values	Category
1	80–100	Mostly ready for preparedness
2	65–79	Ready for preparedness
3	55–64	Less ready for preparedness
4	40–54	Least ready for preparedness
5	<40	Need preparedness

Table 2 Result of the preparedness index

KAP	EP	WS	RM	Total (PI)
0.3	0.53	0.05	0.12	1
77	73	69	70	74

Table 3 Preparedness index in risk zones

Zone	KAP	EP	WS	RM	PI
Red zone	78	74	71	71	75
Safe zone	77	70	57	67	71
Total	77	73	69	70	74

7.2 Preparedness Index According to the Risk Zone and Recommendations

The PI categorized by the risk zone (Table 3) indicates that preparedness of individuals who live in the vulnerable zone (75), is higher than those in the safe zone (71). In each zone KAP records the highest values whereas WS and RM record the lowest values. The knowledge and attitude for tsunami preparedness plans can be identified as high in both zones. WS in safe zone is recorded as the lowest index value in overall. There is a positive correlation between levels of education with the index value of preparedness. Hence, education can be considered as an important factor to increase the response capacity of residents of Padang city against earthquake and tsunami.

7.3 Recommendations for Improving the Emergency Planning (EP)

Minimizing the overlaps and drawbacks in the organizational structure for DRM is crucial for the Padang administration. The research identified that within the organizational structure the short-term employee turnover has been a drawback which disrupt the continuations of the TEP process and proceedings.

81% of respondents did not have an evacuation map in their house, and 73% mentioned that such equipment is also not available at proximity. According to the survey result, 81% already aware of the nearest tsunami evacuation route for safe locations from their house and 67% knew the evacuation route from their working places and schools. The latest versions of the evacuation maps have identified the vertical shelters linked to horizontal evacuation routes. These positive factors need to be improved via an all-inclusive tsunami evacuation plan covering the entire Padang region. Further, the maps should be multi linguistic for the tourist's communities for convenient reference.

Apart from the ability to understand the map, Padang residents are also required to be able to identify the topography aspect to understand the tsunami evacuation map including the following aspects.

1. Ability to identify both the tsunami prone zone and the tsunami safe zone.
2. Ability to locate the place where they live on the evacuation map.
3. Ability to identify the location of vertical shelters.
4. Ability to identify symbols characterizing city landmarks.
5. Ability to comprehend evacuation routes among nodes.

Horizontal evacuation refers to the action of fleeing away from the coast towards the tsunami safe area using the recommended routes. 70% of the respondents are not aware of the tsunami evacuation buildings near their homes, and 58% from their daily activities. Therefore, the Padang local government needs to attain specifically on educating the communities regarding the available and new evacuation routes and assess their capacities to manage emergency conditions.

Vertical evacuation is the act of fleeing toward higher ground, either a hill (natural shelter) or a multi-story building. In Padang, the vertical tsunami shelter buildings which is combined with public facilities, i.e., schools, offices, and mosques consist the capacity to hold 9000 people (Ashar et al., 2014), however, governments, and NGOs need to assess the holding capacity and resistance of the existing buildings before recommending for vertical evacuation centers of TEPs.

7.4 Recommendations for Improving the Warning System (WS)

Learning from the experience of the Aceh Tsunami in 2004, the government made it aware that a sudden low tide after a very strong earthquake is one of the signs of tsunami impact. However, Danny Hilman Natawidjaja (2012) who conducted research at the Laboratory for Earth Hazard - LIPI mentioned that the receding sea water after a strong earthquake may not occur as a sign of a tsunami in Padang City.

Therefore, the WS in Padang needs extra effort to communicate the communities timely for undertaking evacuation measures. People must immediately evacuate from coastal areas to a higher place if an earthquake lasts longer than one minute. The survey result indicated that 68% of the respondents do not have a clear idea regarding the ETA of the first tsunami wave (believed to be more than 30 min). However, the minimum ETA for the city of Padang is 30 min. Therefore, BMKG should provide information about earthquake and a tsunami alert within 5 min or less. After that, PUSDALOPS in Padang and the Government and relevant agencies must decide within 3 min to evacuate and must make the announcement. Upon the receipt of the warning message, the vulnerable communities should make immediate actions to evacuate for safe locations within 5 min. That leaves 17 min for the communities to reach a safe location within a radius of 1.5 km.

7.5 Recommendations for Improving the Resource Mobilization (RM)

The survey result identified that 77% of respondents have never attended any forms of capacity building events about the threat of tsunamis. Dissemination of disaster information needs to be carried out routinely by the government at all levels covering local and tourist communities. Meanwhile, the migrant populations which change almost every year depending on the level of education is an essential element to cover in resource mobilization.

Simulation is one of the ways to evaluate the level of success of some preparedness programs. Several Tsunami Evacuation Simulation activities have been conducted in Padang, but this activity is not routinely carried out, depending on the funds and the organizers. The local government sponsor the simulation once a year. The peoples' interest to take place in evacuation simulation drills are very low (30%). Therefore, the government needs to raise the awareness on the importance of simulation drills for disaster risk management via providing incentives and obligatory terms.

8 Summary of key findings

Padang City tsunami preparedness index for community (PI) demonstrates a value of 74 which represent the category of 'ready for preparedness'. The state of KAP and EP can be considered satisfactory where the state of WS and RM needs a significant intervention for improving the current state on preparedness. Based on the survey findings the key recommendations can be recognized in two aspects. (1.) the use of strengths, (2.) the use of opportunities, to overcome the weaknesses and threats.

The community preparedness and attitude can be considered as a major advantage for adapting TEP in the Padang region. To further advance the knowledge on TEP, the school education system and awareness raising via social and religious centers can be used, especially about self-evacuation, use of evacuation maps and use of essentials kit for evacuation should be emphasized. Structural measures should be developed along with the awareness raising including sufficient evacuation signs and warning sirens corresponding with the legible evacuation maps. The government can take initiatives to identify and convert the existing suitable buildings for temporary evacuation centers both in vertical and horizontal forms and promote self-evacuation of communities to the closest evacuation shelter as soon as a warning message is issued.

As a non-structural measure for TEP improvement the government and NGOs need to work in integrity and mainstream the relevant purviews into a wholistic framework for TEP. A master plan for tsunami response and preparedness is needed for Padang city along with strategies for community engagement in planning and implementation. The international and national opportunities with knowledge and financial support needs to be properly mobilized for the construction of tsunami mitigation measures, evacuation routes and multi-purpose vertical shelters. Further, the international best practices can be adapted to improve the organizational structure for disaster management in Padang and establish policy and strategic directives for disaster risk management. Simultaneously, community participation needs to be encouraged in training workshops and simulation drills and officials needs to be trained as mentors and emergency managers as necessarily. Also, the use of intelligent smart technologies for disaster monitoring and communication needs to be recognized in the tsunami preparedness development.

Along with the research findings, a further research direction is suggested to evaluate the evacuation routes in Padang City attempting to uncover the legalization aspect on the standard of the width of road and the type of road construction.

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Communications for Better Early Warning

Increasing the Capacity of Higher Education to Strengthen Multi-Hazard Early Warning in Asia

Kinkini Hemachandra, Richard Haigh, and Dilanthi Amaratunga

Abstract The Sendai Framework for Disaster Risk Reduction 2015–2030 (SFDRR) recognises the benefits of MHEW systems and enshrines them in one of its seven global targets: "Substantially increase the availability of and access to multi-hazard early warning systems and disaster risk information and assessments to people by 2030". This chapter describes the activities and results from a three-year initiative to strengthen multi-hazard early warning (MHEW) for coastal hazards by developing the capacity of higher education institutes (HEI) in Asia. The CABARET project was established to promote international cooperation on MHEW at the regional level between HEIs in Asia and Europe, and among Asian HEIs. It involved a consortium of fifteen European and Asian HEIs from Bulgaria, Indonesia, Latvia, Maldives, Malta, Myanmar, Philippines, Spain, Sri Lanka and the UK, as well as three non-academic actors who provided a vital link to wider socio-economic perspectives. The consortium of HEIs set out to build capacity, foster regional integration and cooperation through joint initiatives, and share good practices. They also sought to strengthen relations between HEIs and the wider economic and social environment through a specific focus on coastal communities, many of whom are under severe pressure from planned and unplanned development, population growth and human induced vulnerability, coastal hazards with increasing frequency and magnitude, and the impacts of global climate change. This chapter describes the project's efforts to better understand the research and innovative capacity needs across the Asian HEIs and to build their capacity to support the development of a more comprehensive, multi-hazard approach to early warning. The chapter concludes by examining the key achievements of the project, including an increase in innovation capacity and the promotion of regional cooperation.

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1 Introduction

1.1 Coastal Hazards and Multi-Hazard Early Warning

The Asia–Pacific region is regularly labelled as the most disaster-prone in the world due to a long history of both major catastrophic disasters and frequent small and medium-sized events. However, climate change, environmental degradation and other factors have resulted in a risk landscape for the region that is increasingly uncertain. Recent studies and practical experiences have also emphasised the relationship between disasters, climate change and sustainable development. Climate-related hazards are particularly prevalent along coastlines, which is where many Asian cities are located. Urban areas also concentrate risk and many of the region's urban population live in informal settlements. People living informally are the worst affected by disasters because they lack access to basic services and security of tenure, and do not have the voice or means to substantially improve their living conditions.

Effective multi-hazard warning systems (MHEW) are vitally important to address such disaster risk. Traditionally, many countries have been reactive to disasters experiencing significant losses in lives and livelihoods of their citizens. Adoption of the Hyogo Framework for Action (HFA) 2005–2015, and more recently, the Sendai Framework for Disaster Risk Reduction 2015–30 (SFDRR), has led to a paradigm shift in disaster risk management, from emergency response to a comprehensive approach which also includes preparedness and preventive strategies to reduce risk.

The SFDRR recognises the benefits of MHEW systems and enshrines them in one of its seven global targets: "Substantially increase the availability of and access to multi-hazard early warning systems and disaster risk information and assessments to people by 2030".

In responding to this challenge, it has been widely acknowledged that MHEW is more effective when it is integrated within regional and national strategies for enhancing resilience and reducing disaster risks (UN-ESCAP, 2015a, b). Although the Indian Ocean Tsunami Warning and Mitigation System (IOTWMS) and other initiatives have been largely successful in promoting regional cooperation to develop technical hazard detection infrastructure, progress at the national and sub-national level has been far more variable. For example, a review of national reports on recent earthquakes and tsunami threat responses and practice evacuation exercises suggest that there is uneven progress across the region, with some high-risk, low-capacity countries falling behind (UNESCO/IOC, 2019).

There remains the significant challenge of building capacity to sustain the achievements to date and continue to enhance the systems now in place, including detection and warning systems, community awareness and preparedness. There is also a need to build capacity to broaden existing single hazard early warning systems, such as IOTWMS, to provide a comprehensive, multi-hazard framework.

1.2 The Role of Higher Education in Capacity Building

This chapter describes the activities and outcomes from a three-year initiative aimed at building capacity for MHEW through increased regional cooperation among higher education institutes (HEIs).

The role of higher education in supporting capacity building for disaster resilience has been explored in previous studies, including ANDROID (Amaratunga et al., 2015) and CADRE (Amaratunga et al., 2017). Building more resilient coastal communities is increasingly complex, demanding an ever-widening range of skills and input from diverse disciplines. Often, no single individual, institution or discipline will possess all the knowledge, skills and techniques required.

The SFDRR, agreed by member states in 2015, also included a strong call for higher education and the wider scientific community to support the understanding of disaster risk, and promote risk-informed decisions and risk sensitive planning from local to global levels. Researchers and academics, therefore, must work at the regional level, and with policy makers and practitioners, to co-design and co-produce research that can be used effectively. Capacity should be developed through scientific research and development of knowledge bases, advocacy to inform policy and practice, and the provision of education and training that is relevant to the needs of communities at risk.

1.3 EU-Asia Cooperation Among HEIs

The CABARET project (Capacity Building in Asia for Resilience EducaTion), funded by the European Commission's Erasmus + programme, was established to promote international cooperation at the regional level, between HEIs in Asia and Europe, and among Asian HEIs themselves, to improve MHEW and increase resilience among coastal communities. It set out to build capacity, foster regional integration and cooperation through joint initiatives, and share good practices among HEIs in Asia and Europe. In doing so, it sought to strengthen relations between HEIs and the wider economic and social environment through its focus on coastal communities, many of whom are under severe pressure resulting from planned and unplanned development, population growth and human induced vulnerability, coastal hazards with increasing frequency and magnitude, and the impacts of global climate change.

CABARET ran from October 2016 to January 2020 and involved a consortium of fifteen European and Asian HEIs from Bulgaria, Indonesia, Latvia, Maldives, Malta, Myanmar, Philippines, Spain, Sri Lanka and the UK. These HEIs were supported by three non-academic actors who provided links to wider socio-economic perspectives: the Asian Disaster Preparedness Centre (ADPC), UN Ocean Community—Intergovernmental Oceanographic Commission of UNESCO (IOC-UNESCO), and the Federation of the Local Governments Association in Sri Lanka (FSLGA).

The project set out to identify the research and innovative capacity needs across Asian HEIs in Indonesia, Maldives, Myanmar, Philippine and Sri Lanka, and to build capacity in HEIs so that they could contribute to a more comprehensive, multi-hazard approach to early warning.

In order to achieve this goal, the project had five main objectives: (1) identify intra and inter regional cooperation capacity needs across partner country HEIs for the development of more effective MHEW; (2) create an innovation hub for resilient coastal communities, promoting scientific cooperation and knowledge transfer in Higher Education within Asia, and between Asia and Europe on MHEW; (3) develop a capacity building roadmap to address regional gaps and priorities; (4) explore, promote and initiate opportunities for fruitful university partnerships with socio-economic actors in coastal communities; and (5) develop innovative multi-disciplinary training courses tailored for rapid skill (knowledge, qualifications,) acquisition for professional teams involved in MHEW at the national and regional level.

The remainder of this chapter describes the major activities carried out by the project and the outcomes that have contributed to capacity building for MHEW and resilience building in the Asian region.

2 Understanding National and Regional Capacity Gaps

The project team carried out a series of literature reviews, workshops, and national and regional analyses. These were used to inform the workplan and capacity building goals of CABARET. They provided a better understanding of the current status of MHEW in the region and established the priorities for capacity building among HEIs.

2.1 Conceptual Framework

A detailed capacity assessment was conducted to ensure that the project supported national and regional priorities. The assessment was based on a capacity framework with fifteen critical areas that support implementation of the global agreements on sustainable development, climate change and disaster risk reduction, and also linked to HEIs' roles in education, advocacy and knowledge development: capacity building / training; governance; communication; local authorities; education and awareness; planning and preparedness; technical and scientific; resources and infrastructure hazard warning and forecasting; political recognition; stakeholder participation; mainstreaming DRR/CCA into development planning; and hazard monitoring. The framework was jointly developed by the consortium and based on HEI priorities in each country and a review of peer-reviewed journal articles and grey literature. The review also addressed three key questions: What are the global policy drivers for MHEW? What are the regional drivers for MHEW? What are the key enablers/areas of capacity for effective MHEW at the regional and national level? Workshops in Sri Lanka and Spain, which included participation by over thirty experts from fifteen HEIs, were used to review and finalise the framework (Haigh et al., 2018). The initial framework underpinned a series of surveys at the national (Indonesia, Maldives, Myanmar, Philippines, Sri Lanka) and regional (Asia) levels.

2.2 National and Regional Capacity Surveys

In each Asian partner country, a national position paper was written to establish the status of MHEW in their country, and the role and status of HEIs in supporting capacity building. The in-country research teams conducted eighty one interviews and four focus group discussions in Indonesia, Maldives, Myanmar, the Philippines and Sri Lanka. They also published five separate national position papers (Hettiarachchi et al., 2018; Josol et al., 2018; Kyaw et al., 2018; Rahayu & Opiyandri, 2018; Shadiya, 2018). A further online survey was conducted among 136 practitioners, policy makers, academics and experts to provide a region wide perspective. A summary of these analyses was published in a regional position paper (Haigh et al., 2019) and a book chapter on the role of higher education institutions toward effective multi-hazard early warnings in Asia (Hemachandra et al., 2020).

In 2018, CABARET was also invited to support Working Group 1 of the Intergovernmental Group of the Indian Ocean Tsunami Warning and Mitigation System (ICG/IOTWMS) and its Task Team on Capacity Assessment of Tsunami Preparedness (TT-CATP). The survey gathered responses from twenty-one official contact points to better under the status of capacity on tsunami preparedness in the Indian Ocean. It was published as Intergovernmental Oceanographic Commission Technical Series 143 ICG/IOTWMS Status Report Capacity Assessment of Tsunami Preparedness in the Indian Ocean 2019.

2.3 Capacity Gaps Among HEIs in Asia

The various literature reviews and national & regional analyses revealed some common capacity gaps among HEIs in Asia that were undermining their efforts to support the development of more effective multi-hazard warning. These were summarised under six key areas, as illustrated in Table 1 funding and resources; political and policy support; self-interest and awareness; coordination; knowledge; and communication.

Table 1 Summary of capacity gaps among HEIs in Asia

Funding and resources Availability of funding/budget Equipment and technology Cost of higher education Capacity building programmes	*Coordination* National Regional Socio-economic actors
Political and policy support Policies and procedures Regional disputes Political will and prioritisation Roles and responsibilities Access to information	*Knowledge* Educational programmes Balance of theory and practice Skills Innovation Availability of national/regional databases
Self-interest and awareness Initiatives Interest Output (publication) rather than outcome driven Understanding of user needs	*Communication* Communication channels Public engagement Advocacy

3 Capacity Building of Higher Education

The conceptual framework and results from the various national and regional analyses provided a basis for the project's capacity building activities.

3.1 Innovation Hub

The five in-country analyses and regional paper prepared by CABARET identified the need for a cooperative mechanism on MHEW so that countries will be better able to share good practices, expertise and capacities in assessing risks, developing sustainable monitoring and warning services, creating proper dissemination and communication systems, and coordinating with communities to increase response capabilities.

A regional innovation network on MHEW was established among the fifteen partner institutions to assist in strengthening MHEW at all levels in Asia, while also facilitating knowledge transfer with Europe and other regions. The network set out to influence policy and decision-making processes as a means to meet the cognitive and normative challenges in positioning MHEW systems and preparedness in the wider context of social change. Thematic areas for the network were identified to promote innovation, and disseminate knowledge, lessons learnt and experiences. The forum also sought to further stakeholder engagement, capacity building and knowledge sharing, and build upon the priorities identified in the regional position paper. The network would achieve its objectives through sandpit events, short term scientific missions and training workshops.

Sandpits were held in the form of interactive workshops over multiple days. They had a highly multidisciplinary mix of participants from across the fifteen partner institutions to drive lateral thinking and radical approaches that address major regional challenges in MHEW, whether they be related to policy, research or education. The sandpits were intended as intensive discussion forums where free thinking is encouraged to delve into the problems on the agenda to uncover innovative solutions. Six sandpit groups were established to address specific challenges around: small island states; MHEW; education for disaster resilience; public–private partnerships for resilient harbours; evacuation planning for marginalised groups; and, risk assessment at the local level. These groups organised fourteen capacity-building activities with more than 230 participants including many forms of training and a mentoring programme. They also facilitated seven EU-Asia and Asia-Asia exchanges involving thirty-five people.

3.2 Training

Four international training workshops were organised on the topic of MHEW and disaster resilience in coastal communities. Over 400 participants from the partner HEIs attended the events in Sri Lanka, Myanmar, Philippines and Indonesia. The events included resources persons from different academic disciplines, as well as those representing government and non-government actors. Field visits to disaster affected communities and meetings with national and local disaster management related actors involved in early warning were used to reinforce the policy and practical implications of the scientific discussions. In the Philippines, a secondment activity was organised with the Lian Batan municipality to understand local challenges and requirements, as well as consider how relations between HEIs and socio-economic actors could be strengthened.

A programme on *Mentoring for Resilience* was conducted in the Philippines by the disaster resilience education sandpit group. The event provided the opportunity for graduate students who work on disaster risk and resilience to share their current research and have one-on-one sessions with international experts, thereby promoting knowledge transfer internationally and also across disciplines.

3.3 Short Term Scientific Missions

More than 100 academics and researchers took part in short term scientific missions between Asia and Europe, and within Asia. These provided opportunities for academics and researchers at HEIs to share their structures, curricular, teaching and research policies and practices, as well as engage with socio-economic actors form other countries. They also enabled the design and conduct of joint research programmes that resulted in a series of jointly authored research papers.

3.4 Curriculum Development

The project developed a series of four open educational resources covering fundamental aspects of multi-hazard early warning and disaster resilience. The courses were designed to bring together different disciplinary perspectives and share global case studies. The four courses covered disaster preparedness, coastal hazards, science and technology for disaster risk reduction, and community-based disaster risk management. The Maldives is already adopting the courses for inclusion in a newly launched disaster management undergraduate programme, the first of its kind in the country.

3.5 Advocacy

Seven policy dialogues were conducted, for examples at the national level with the Association of Disaster Risk Management Professionals in Colombo, Sri Lanka and at the regional level with key stakeholders at the ICG/IOTWMS meeting, in Jakarta, Indonesia.

At the international level, CABARET partnered with the 7th, 8th and 9th International Conferences on Building Resilience, held in Thailand (300 + participants), Portugal (200 + participants) and Indonesia (180 + participants). These provided key dissemination forums for the project. In Indonesia, the event also involved policy dialogues and panel discussions, workshops and keynote addresses with national and regional actors, including BMKG, BNPB, ADPC and ICG-IOTWMS. A panel discussion was also organised at the ASCENT Festival in Sri Lanka. The panel addressed MHEW and technology, and included the participation of major Sri Lankan actors from government and the private sector, including the Disaster Management Centre and Dialog mobile communications.

On a global scale, partner institutions held a range of events and activities across Europe and Asia linked to MHEW and to coincide with the International Day for Disaster Reduction (IDDR). The project was also represented at the IOC/UNESCO Symposium, held in the UNESCO Headquarter in Paris-France on 12–14 February 2018, and at the Multi-Hazard Early Warning Conference held as part of the UN Global Platform in Cancun, Mexico in May 2017.

4 Outcomes from the Capacity Building

The CABARET initiative has helped to build capacity, and foster regional integration and cooperation through joint initiatives, sharing of good practices and cooperation among HEIs in Asia and Europe. Collectively, through the capacity building activities, the fifteen partners have:

- Supported a regional survey of tsunami capacity among twenty-one countries of the Indian Ocean Tsunami Warning and Mitigation System
- Published five national position papers and one regional position paper that summarise the status of MHEW and role of higher education in supporting capacity building
- Published over eighty joint scientific papers
- Organised six international meetings and four multi-disciplinary workshops involving over 400 participants
- Facilitated eight EU-Asia and Asia-Asia exchanges involving over 100 people
- Formed six special interest groups that facilitated fourteen capacity building activities
- Held a mentoring programme
- Developed four open educational resources
- Secured four externally funded spin-off projects and submitted over ten joint research proposals
- Conducted eight policy dialogues to strengthen cooperation among HEIs and other stakeholders

The most significant contributions of the project have been in relation to innovation capacity and regional cooperation.

4.1 Increased Innovation Capacity

It is an imperative to take an integrated and holistic approach to early warnings for multiple hazards and risks tailored to user needs across sectors. Given the transboundary nature of most natural hazards, international and regional collaboration and multi-stakeholder partnership is necessary at all levels. CABARET is innovative through contributing to the development of a prominent "voice" for early warning at the international level that could raise the visibility and advance the agenda of MHEW regionally worldwide and advocate the usefulness of MHEW in international platforms and among key stakeholders, including donors, and across all sectors. It has helped to develop regional innovation infrastructure that promotes scientific cooperation and knowledge transfer.

Like many fields, disaster research has typically been conducted in 'silos', where each discipline addresses the problem from their own perspective, and with limited cooperation with others. However, the complex nature of disaster risk, including the combination of natural, physical and socio-economic vulnerabilities that leave many communities exposed, has shown this approach to be unsuccessful in promoting disaster resilience. The SFDRR highlights the shortcomings of existing practices, including the lack of researchers and professionals that have experience of multi-disciplinary environments, or who are equipped with the skills and abilities to tackle the complexity of disaster risk in their research.

The innovative element of CABARET has been to address this problem through bringing researchers from traditionally separate disciplines together in a multidisciplinary environment and to provide researchers with the skills and experience to conduct disaster resilience research. For example, the innovation hub has stimulated cooperation among partners on several priority areas for Asia that were identified through the capacity gap analyses carried out at the national and regional levels. These included: public–private partnerships in major infrastructure projects such as ports; evacuation planning for marginalised groups; multi-hazard early warning; sustainability and resilience in the built environment - remote regions, island archipelagic states; local government and risk mapping; and disaster resilience education. These groups were all multi-institution, international and multi/inter disciplinary, providing fresh perspectives on emerging challenges, but also sharing practices across the region. This is demonstrated by the large number of research papers and outputs produced by these groups and which provided comparative studies across the CABARET partnership.

A large proportion of disaster resilience research focused on Asia is often produced in other regions (e.g. Europe and North America). This project helped to build capacity for Asian HEIs to conduct their own domestic research effectively, as well as to promote international collaboration through strengthening the links between partner institutions and HEIs in Europe. The project has been innovative in its focus on knowledge sharing between partners as opposed to more traditionally employed knowledge transfer approaches. Furthermore, in order to deliver targeted research with impact, the involvement of industry and policy makers is important, a fact that is becoming more well recognised but one that remains frequently overlooked within HEIs. Through a dedicated work stream on socio-economic actors, CABARET has contributed to building the linkages needed to better address the needs of society through research. A further innovative aspect of CABARET has been to develop novel training materials on emerging challenges that are available for open access on a dedicated KnowledgeHub. These teaching, learning, and research resources reside in the public domain and have been released under an intellectual property license that permits their free use and re-purposing by others.

4.2 Enhanced Regional Cooperation

The CABARET project involved fifteen institutions from ten different countries. The consortium included six institutions from five European countries (Bulgaria, Lativa, Malta, Spain, the UK) and nine institutions from five Asian countries (Indonesia, Maldives, Myanmar, Philippines and Sri Lanka). On the regional level, new linkages were made through engagement with regional efforts on tsunami early warning, including collaboration with IOC-UNESCO. Activities were co-led by one institution from Europe and one from Asia in order to ensure inter-regional working. A secondment programme enabled Asian partners to visit European institutions and other Asian partners to develop cooperative relationships. From the point of view of contributions towards regional integration and cooperation between different regions of the world, CABARET had provided a very strong platform. A series of sandpit events allowed consortium members to develop new project proposal ideas together around six regional priorities, as well as combine international partners and multidisciplinary teams. Over ten new collaborative project proposals in related areas have been developed and submitted. These have provided a strong basis for sustainability so that partners can continue the collaborations beyond the life of the original project.

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Rainfall Triggered Landslide Early Warning System Based on Soil Water Index

H. G. C. P. Gamage, T. Wada, K. P. G. W. Senadeera, M. S. M. Aroos, and D. M. L. Bandara

Abstract Fourteen districts were identified as landslide prone in Sri Lanka. These districts fall in the wet and intermediate climatological zones where annual rainfall is over 2000 mm. Short term heavy rainfall and long term cumulative rainfalls are active factors for landslide occurrences. In this study, to enhance the landslide prediction capacity and accuracy, two indices were analyzed; Short Term Rainfall Index—1.5 h. half period Working Rainfall and Long-Term Rainfall Index—Soil Water Index. Also, regional critical Soil Water Index values were evaluated for the analysis of regional geological and other parametric impact on landslides. Hydrological Tank Model simulations were used to calculate Soil Water Index and to predict landslides with snake curves and probability curves. In regional aspect, tank model parametric analysis was carried in determination of suitable parameter set for each soil conditions. Rainfall intensity acts as the main contributing factor for Soil Water Index. With probability curves, better predictions were obtained on regional based soil water index of greater than 100 values to identify the landslide occurrences even though the Short-Term rainfall did not exceed 10 mm. Region-wise Critical Soil Water Indexes were obtained by critical lines with soil parameters derived for Sri Lankan soil conditions. Better practices on landslide early warnings could be performed through these derived regional long-term Soil Water indexes. As a future development, it is expected to develop warning levels based on these critical values.

1 Introduction

Quantifying the probability of landslide risk associated with heavy rainfall is necessary for a mountainous country (Shuin et al., 2014) like Sri Lanka to mitigate the damages for people and property due to landslide occurrences. Rainfall thresholds

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for slope failures are essential information for establishing early-warning systems and for disaster risk reduction (Lin et al., 2020). National Building Research Organisation uses cumulative rainfall values for predicting landslide early warnings. 24 h cumulative rainfall is used for issuing landslide early warnings and categorizing them in to levels of risk: Watch for 75 mm and above, Alert for 100 mm and above, and Evacuation for 150 mm and above. These levels of risk were derived by previous researches. Rainfall affects for landside events in short term precipitation and long term precipitation. Later researches carried in finding the best long term and short term rainfall indices. As a resultant 1.5 h. half period working rainfall (1.5WR) and Soil water index were declared as the best short term rainfall index and the long term rainfall index respectively (Rajapaksha et al., 2019).

For enhancing the existing landslide early warning system, the concern was given on the soil water balance triggered by the rainfall in which represented by the soil water index (SWI). The objective of this study is to derive regional base critical SWI values as threshold values for issuing landside early warnings.

The Soil Water Index provides estimations on average amounts of water stored in the soil. Application of SWI helps to clarify the risk of landslide. Rainwater penetrates through the ground surface and discharges into the rivers or flows into the deeper ground. As the amount of water stored in soil increases, the risk of land slope collapse increases (Japan Meteorological Agency, 2018). Tank model which commonly used to estimate the relationship of rainfall and runoff is used for the SWI calculation. Tank Model is a conceptual model which simulates the moving behavior of water in the soil layers including runoff, infiltration and percolation (Hsu et al., 2018). Tank model used in this study consist of three tanks (Matlan et al., 2018) downward along the vertical soil profile namely: surface runoff, Intermediate and Ground water outflow (Fig. 1). At different levels of soil depths, different soil textures have various values of rates of discharges and infiltrations. In the tank model, each tank has a side outlet representing outflow to the surrounding soil and a bottom outlet representing outflow to deeper ground. Output from the side outlet of the first tank corresponds to surface runoff, that of the second tank corresponds to intermediate flow, and that of the third tank corresponds to base flow (Ground water outflow). Input to the first tank corresponds to rainfall, and input to the second and Third tanks is output from the bottom outlet of the upper tank (infiltration runoff) stored in soil of certain areas, helping to clarify the risk of landslide-related incidents caused by heavy rain (Japan Meteorological Agency, 2018).

The Japanese derived parameter sets including three parameter sets (Hsu et al., 2018) were used to study the regional characteristics of the moving behavior of the water. The three parameter sets were calibrated using mountainous small sub basins in Japan (Ishihara & Kobatake, 1979). One of the parameter set is utilized to evaluate landslide risks and practically applied to issue landslide early warnings by Japan Meteorological Agency and local governments. Therefore, applicability of the parameter sets for landslide warnings in Sri Lanka was evaluated in this study by validating the parameters based on Sri Lankan geological conditions. P1 is a moderate parameter set calibrated in Granite-dominant catchments. P2 parameter set

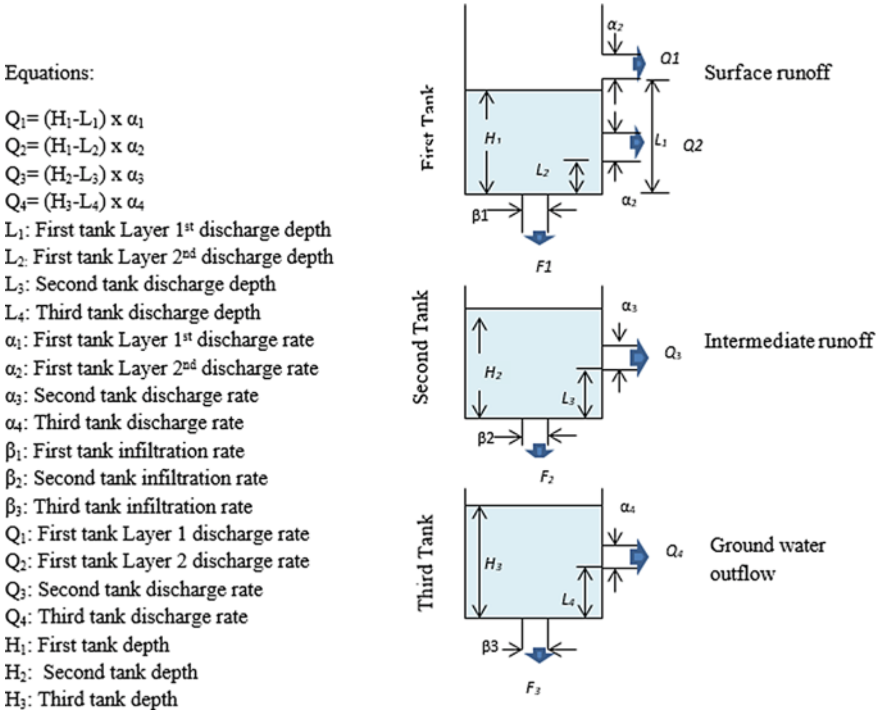


Fig. 1 Tank model

is for basins with gentle discharge increase and small discharge peak; P3 parameter set is for basins with rapid discharge increase and large discharge peak (Table 1).

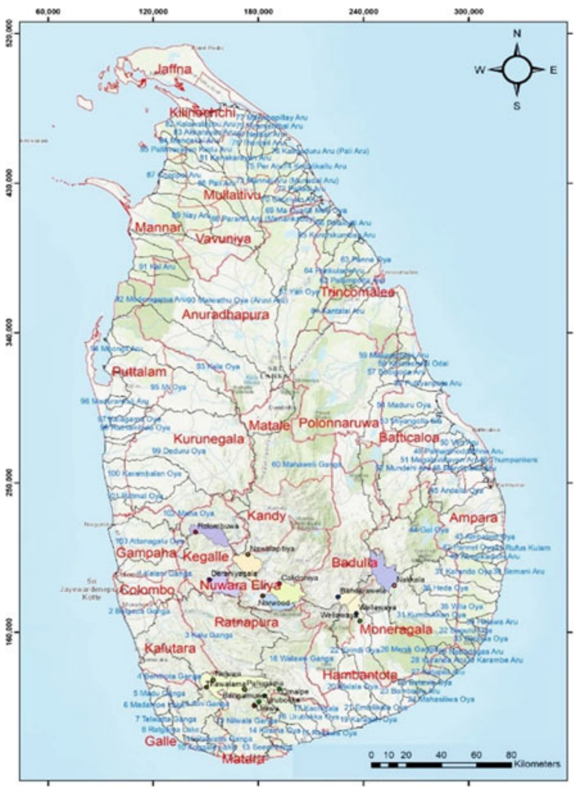
1.1 Study Area

In Sri Lanka, 14 districts; Badulla, Ratnapura, Kandy, Nuwara Eliya, Kegalle, Kurunegala, Matale, Kalutara, Galle, Matara, Hambanthota, Moneragala, Colombo and Gampaha, have been identified for being prone to landside risk. Figure 2 shows the sub basins derived by using ArcGIS for the selected discharge gauging stations functioning under the Department of Irrigation. From this study area, it covers almost all the districts except Matale, Kurunegala, Colombo, Gampaha and Hambanthota. Few of the sub basins spread over two or more districts. Some of the sub basins consist of sub catchments (Table 2).

Table 1 Japanese parameters of the tank model

Area type	L_1	L_2	L_3	L_4	S_1	S_2	S_3	α_1	α_2	α_3	α_4	β_1	β_2	β_3
P1 (moderate peak, Granite)	60	15	15	15	0	20	30	0.15	0.1	0.05	0.01	0.12	0.05	0.01
P2 (gentle peak, Paleozoic)	75	30	5	15	0	20	30	0.15	0.1	0.05	0.01	0.12	0.04	0.01
P3 (sharp peak, tertiary and quaternary)	40	15	5	15	0	20	30	0.15	0.1	0.05	0.01	0.12	0.04	0.01

Fig. 2 Study area; the distribution of sub basins



2 Materials and Methodology

2.1 Data Collection

Secondary data were used in the process of the analysis. The data collected for the analysis are tabulated in Table 3.

2.2 Process of Analysis

In the process of analysis, the flow of the tasks carried in this study mainly focused on developing the existing system of issuing landside early warnings focusing on SWI values which triggered by rainfall. Past data records of real time 30 min. rainfall data were collected for calculating 1.5 WR and the SWI for each catchment and sub basin. ArcGIS software was utilized for deriving sub basins and catchments of sub basins using Thiessen polygon and for the calculation of area of the sub basins which are

Table 2 Study area; sub basins for the analysis

Sub basin	Sub catchments	Bordering districts	River basin	Area (km^2)
Norwood	–	Nuwara Eliya, Ratnapura,	Kelani river	92.47
Deraniyagala	–	Kegalle	Kelani river	154.49
Holombuwa	–	Galle, Kalutara, Ratnapura, Matara	Gin gaga	Neluwa-171.891 Pallegama-190.727
Thawalama	Neluwa Pallegama	Matara, Ratnapura	Nilwala	Bengamuwa-13.59 Urubokka-35.83 Olampe-26.36
Urawa	Bengamuwa Urubokka Olampe	Moneragala Badulla	Kirindi	Wellawaya-95.62 Bandarawela-75.17
Wellawaya	Wellawaya Bandarawela	Moneragala Badulla	Kubukkan Oya	217.29
Nakkala	–	Nuwara Eliya Ratnapura	Mahaweli	182.46
Calidoniya	–	Kandy, Nuwara Eliya	Mahaweli	185.46
Nawalapitiya	–	Kandy, Nuwara Eliya	Mahaweli	185.46

Table 3 Data used in the analysis

Task	Tank model parameters calibration and validation	SWI calculation (deriving critical lines and critical SWI values)
Data	Past 30 min. rainfall data records for derived sub basins and sub catchments from year 2016 to year 2019	Past 30 min. rainfall data records for derived sub basins and sub catchments from year 2014 to year 2020
	Observed hourly discharge data from year 2016 to year 2019	Past Landslide records from 2014 to 2020
	Other related data (geology, elevation, land use) maps	
	Tank model parameter data	

utilized on the tank model. When deriving catchments, the sub basin was divided into the number of sub partitions considering the consisting number of automated rain gauge stations within the sub basin.

A calibration process was carried out with a final validation process to certify the regional wise changes in tank model parameters. These confirmed, tested parameters were used for deriving the regional SWI critical values useful for issuing landside early-warnings. In testing the parameters, the patterns of the observed discharges and calculated discharges were graphically compared and analyzed statistically. RMSE (Root Mean Square Error) and NSE (Nash–Sutcliffe model efficiency coefficient) (Vasconcellos et al., 2020) were used as the statistical analyzing methods. RMSE (Root Mean Square Error) is used to express how close the observed data points are to the model's predicted values. The Nash–Sutcliffe efficiency (NSE) is a normalized statistic that determines the relative magnitude of the model's simulated variance compared to the measured data variance.

2.2.1 Calibration of the Tank Model Parameters

A developed macro program was used to analyze the hydro graphs of simulated and observed discharges in each basin to identify the best matching parameter-set.

Tank model parameters were calibrated with the observed and calculated discharges of the sub basins. In calculating the sub basin discharges, the average rainfall time series in the sub catchments were inputted to the tank model. Calculated discharges of the sub catchments were added together to obtain total discharges of the sub basins which consist of sub catchments.

The patterns of the simulated discharges and observed discharges were compared by plotting hydro graphs for the selected periods which had heavy rainfall.

The values of simulated and observed were statistically tested using RMSE and NSE for the selection of the identical parameter set which RMSE is closer to zero and NSE is closer to 1 (Vasconcellos et al., 2020).

2.2.2 Rainfall-Landslide Correlation Analysis Using SWI Calculations

A developed macro program was run to calculate SWI values and deriving critical lines and to define critical SWI values. The function of SWI was used to give an indication on the level of soil moisture in the area of landslide. The balance water quantity along the vertical soil profile was assumed as SWI value in the calculation. The outputs of SWI calculation were graphically represented via snake curves. The SWI equals to the total storage volume of three tanks laid vertically in series. The storage volume on each tank can be calculated using the following equations: (Sugawara, 1972).

$$\mathrm{I}_{1(\mathrm{t})} = \beta_1 \times \left(\mathrm{H}_{1(\mathrm{t})} - (\mathrm{L}_1 + \mathrm{L}_2)_{(\mathrm{t})}\right);\ (\mathrm{I}_1,\ \mathrm{I}_2,\ \mathrm{I}_3 : \text{ Infiltration rates of Tank 1, Tank 2 and Tank 3})$$

$$\mathrm{I}_{2(\mathrm{t})} = \beta_2 \times \left(\mathrm{H}_{2(\mathrm{t})} - \mathrm{L}_{3(\mathrm{t})}\right)$$

$$I_{3(\mathrm{t})} = \beta_3 \times \left(\mathrm{H}_{3(\mathrm{t})} - \mathrm{L}_{4(\mathrm{t})}\right)$$

$$\Delta\mathrm{S}_1 = \mathrm{R}_{\mathrm{F(t)}} - \mathrm{Q}_{1(\mathrm{t})} + \mathrm{Q}_{2(\mathrm{t})} - \mathrm{I}_{1(\mathrm{t})};\ (\Delta\mathrm{S}_1,\ \Delta\mathrm{S}_2, \Delta\mathrm{S}_3 : \text{ Water retention in Tank 1, Tank 2 and Tank 3})$$

$$\Delta\mathrm{S}_2 = \mathrm{I}_{1(t)} - \mathrm{Q}_{3(\mathrm{t})} - \mathrm{I}_{2(\mathrm{t})}$$

$$\Delta\mathrm{S}_2 = \mathrm{I}_{2(t)} - \mathrm{Q}_{4(\mathrm{t})} - \mathrm{I}_{3(\mathrm{t})}$$

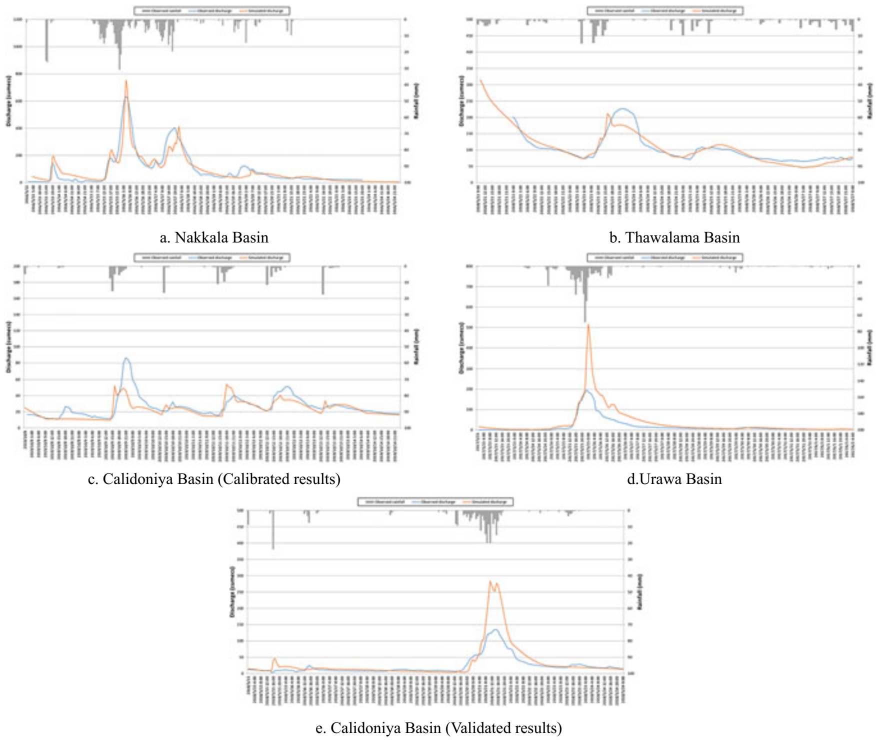
$$\mathrm{SWI} = \Delta\mathrm{S}_1 + \Delta\mathrm{S}_2 + \Delta\mathrm{S}_3.$$

The calculated 1.5 WR and SWI time series and points of landslide occurrence were plotted together on snake curve charts to identify correlations between the landslide occurrence and triggering rainfall. Snake curve charts are scatter line charts consisting of short term rainfall index axis (*Y* axis) and long term rainfall index axis (*X* axis). Finally, CL was defined on a boundary of landslide occurrence and non-occurrence using Gaussian distributions.

3 Results and Discussion

3.1 Parameter Calibration and Validation

Based on the hydrographs as illustrated in Fig. 3a–e fittingness of parameter sets analyzed were tabulated in the Table 4. The regional parameter sets were certified depending on the RMSE values and NSE values. The parameter calibration was done by using the time series of the largest rainfall events from 2016 to 2019; moreover,



a. Nakkala Basin

b. Thawalama Basin

c. Calidoniya Basin (Calibrated results)

d.Urawa Basin

e. Calidoniya Basin (Validated results)

Fig. 3 Graphical representation of simulated discharges (Orange color) and observed discharges (blue color) with the real time observed rainfall (grey color)

Table 4 Analysis of tank model parameters

Basin	District	Parameter sets obtained by calibration with major rainfall events		Parameter sets obtained by validation with minor rainfall events		Defined parameter set for each basin
		Parameter	NSE	Parameter	NSE	
Holombuwa	Kegalle	P3	0.63	P1 P3	0.71 0.63	P3
Nawalapitiya	Kandy, Nuwara Eliya	P3	0.60	P3	0.30	P3
Nakkala	Moneragala	P3	0.85	P1 P3	0.44 0.40	P3
Wellawaya	Moneragala	P3	0.71	NA/(P1)	(−0.88)	P3
Deraniyagala	Kegalle	P1 P2 P3	0.61 0.66 0.56	P2 P3	0.29 0.35	P2
Norwood	Nuwara Eliya	P2	0.60	P2	0.32	P2
Thawalama	Galle, Kalutara, Rathnapura, Matara	P2	0.83	P2	0.28	P2
Urawa	Matara, Ratnapura	N/A(P2)	(−0.24)	N/A(P2)	(−0.69)	P2
Caildoniya	Nuwara Eliya	N/A (P1)	(−0.18)	P1	0.45	P1

the parameter validation was done by using minor rainfall event data in 2019. The parameters in 7 basins of the total 9 basins showed reasonable reproducibility of the river discharge in the calibration periods (Table 4, NSE: 0.60–0.85). On the other hand, the NSE values in the validation periods were relatively low. It suggests that the tank model simulation is reasonable for major rainfall events in the calibration periods, but is relatively imprecise for minor rainfall events in the validation periods. The purpose of this analysis is to utilize the tank model for landslide early warnings. Therefore, accuracy during major rainfall events is critical for the purpose. NSE values of the 2 basins were negative even during major rainfall events in the calibration periods. However, it seems to be caused by overestimation of rainfall amount. Figure 3d, e shows the hydrographs of Urawa and Calidoniya in the calibration periods. The exceeding of simulated discharge was generated by the high observed rainfall. This observed rainfall values are assumed as overestimations, because total rainfall amounts were much higher than the amount of observed discharge. It seems that the rainfall gauging stations in the basins observed severe rainfall which occurred in a limited narrow area in a short period. Focusing on the increase and decrease rate of discharge except the peaks of rainfall, the trends of discharge increasing and decreasing have similar gradient in both simulated and observed discharge (Fig. 3d, e). Hence, it was concluded that the parameter sets of the tank model are reasonable to be applied for landslide early warnings during major rainfall events in Sri Lankan basin.

Hygrograph of discharges of Nawalapitiya basin (Fig. 3a) represents the characteristics of P3 parameter set. This parameter set create a sharp peak at a highest discharge. At the same time, hydrograph of discharges of Thawalama basin (Fig. 3b) represents the characteristics of P2 parameter set which give gentle peak discharges while the hydrograph of discharges of Caledonia basin (Fig. 3c) represents the characteristics of P1 parameter set which generate moderate peak discharges.

Figure 3a–e represent the time series hydrographs of discharges; *y axis Left- side discharge (cumecs), y-axis Right-side Rainfall (mm)*) at Nakkala Basin, Thawalama Basin, Calidoniya Basin *(calibrated results),* Nakkala Basin and Calidoniya Basin *(validated results).*

These parameters depend the on the geology, slope, land use, land cover and etc. In the analysis of geology in the sub basins, as an overall, the gneiss is the popular geology in the study area. With few differences, a similar geology distribution is seen in the respective basins. Therefore, the difference of tank model parameters in the basin is seemingly caused by other factors. The basins located in the southern area is the P2-gentle peak area; whereas, the basins in northern area is P3-sharp peak area. The mean slope in the P2 basins (15.4°) is steeper than P3 (13.7°) even though the discharge peaks in P3 are sharp. Thus, it seems that land cover and rainfall pattern affect the difference of runoff characteristics. Large amount and long period rainfall in the southwest slopes of Sri Lanka is usually caused by southwest monsoon. The rainfall causes dense forest and high infiltration; eventually, relatively gentle discharge peaks are seemingly generated in the southern area.

The clarified parameters mentioned above in Table 4 were used to calculate SWI and determine Critical Lines.

3.2 Rainfall-Landslide Correlation Analysis

The calculated 1.5 WR and SWI time series and points of landslide occurrence were plotted together on snake curve charts and time series charts to identify the rainfall-landslide correlation trigged by rainfall.

The calculated results of 1.5 WR, SWI, equal rainfall probability lines and disaster records at nine representative sub basins of river basins are shown on the snake curve charts of automated rainfall gauging stations within or closer to the derived sub basins operated by National Building Research Organization of Sri Lanka which are respectively located in the central hills, southeastern, northwestern, southern and southwestern sub-area of the study area. Calculated equal probability lines were also plotted together on the snake curve charts (Fig. 4).

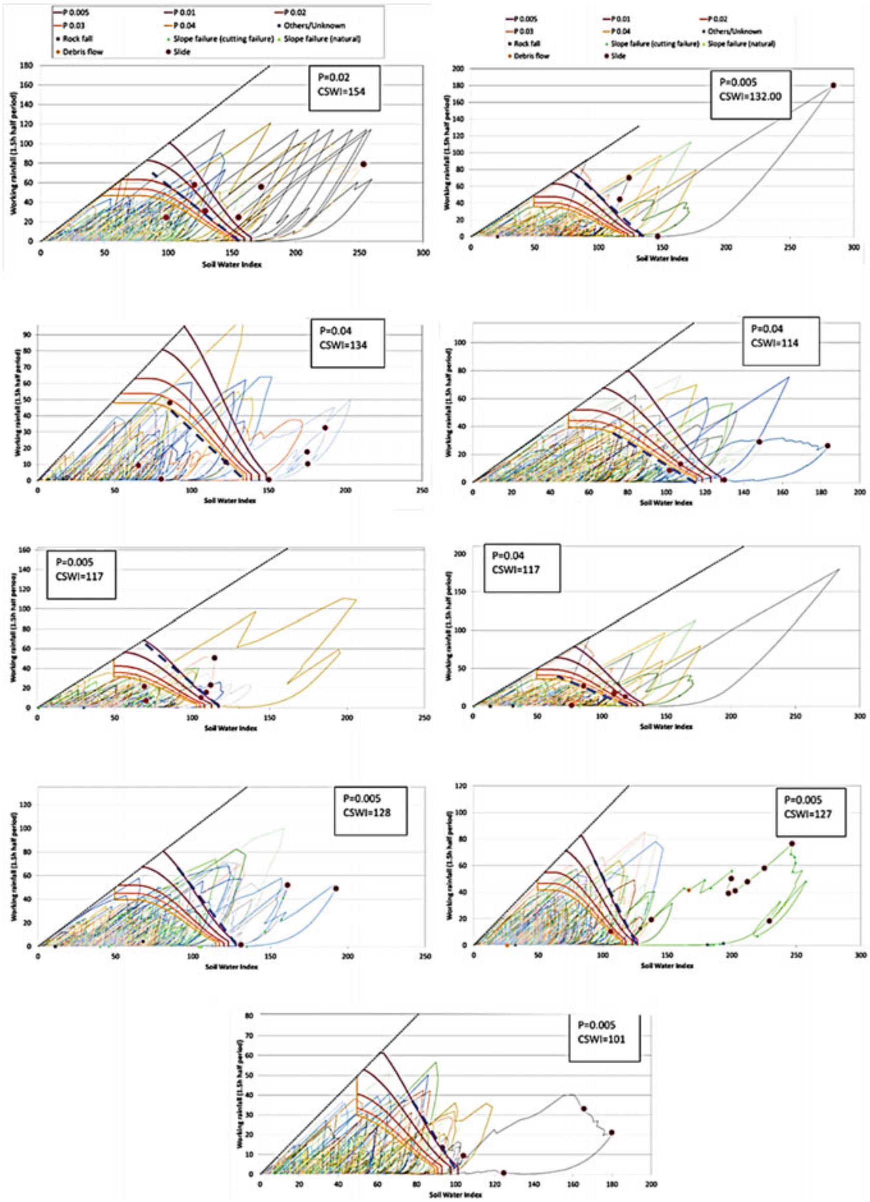


Fig. 4 Regional critical Lines derived by probability curves Gaussian distribution and determined CSWI values *x* axis-SWI values *y* axis

Table 5 Soil Water index values with probability lines determined by Gaussian distribution

Basin	Boundary districts	Probability of critical line using Gaussian Distribution (p value)	Critical SWI
Calidoniya	Nuwara Eliya, Ratnapura	0.005	132
Norwood	Nuwara Eliya, Ratnapura	0.04	117
Holombuwa	Kegalle	0.04	134
Deraniyagala	Kegalle	0.02	154
Nawalapitiya	Kandy, Nuwara Eliya	0.005	117
Nakkala	Badulla, Moneragala	0.04	114
Wellawaya	Badulla, Moneragala	0.005	101
Thawalama	Galle, Matara, Ratnapura, Kalutara	0.005	128
Urawa	Matara, Rathnapura	0.005	127

As illustrated in Fig. 4a–i represent the SWI snake curve charts of Deraniyagala basin, Calidoniya basin, Holombuwa basin, Nakkala basin, Nawalapitiya basin, Norwood basin, Thawalama basin, Urawa basin and Wellawaya basin, respectively.

Critical lines (represent in blue dashed lines in Fig. 4.) were determined by selecting the probability lines on a boundary of landslide occurrence and non-occurrence using Gaussian distributions. For some basins, the critical line was determined on boundary of landside less occurrence and high frequent occurrence where the minimal occurrences take place below probability lines.

Table 5 shows the estimated critical value of SWI and *p* values of equal probability lines of estimated critical lines. The critical SWI ranged from 101 to 154. Even if the 1.5 WR is lower than 10 mm, the past landslides were caused by the high SWI condition. The equal probability line of 0.005 *p* value was determined as a critical line at 5 basins out of 9 basins.

Heavy rainfalls experienced at South West Monsoon (May–September) and North East Monsoon (December–February). Generally, in these periods, the heavy rainfall events continue for more than 10 days. Hence the cumulative rainfall is higher in the regions which affected by heavy rainfall, water retention in the soil increases and reaches to saturated level. After the saturation of soil water, the excess rainfall directly impacts on the slope stability. High values of SWI have a significant impact on destabilizing the slope. As an overall, the determined Critical Soil Water Indexes (CSWI) are above 100. Therefore, at a heavy rainfall event, if the SWI exceeds the limit of hundred, a certain landside occurrence risk could be expected in the landside prone regions.

4 Conclusion

Destabilization of slope depends on rainfall intensity, steepness of terrain and soil water content. Both the Short-term rainfall index (1.5 h. half period Working Rainfall) and the Long-term rainfall index (SWI) are useful for measuring the impact of short term and long-term rainfall intensities for the occurrence of landsides. Monsoonal activities directly impact on increasing the soil water storage due to the continuous heavy rainfall. A reasonable estimation of soil water amount could be obtained by SWI within the rainy season. The minimum regional threshold value of SWI for the occurrence of landslides is hundred. The range of regional SWI threshold values varies in between 100 and 160 for Sri Lankan soil texture for destabilizing the slopes. The threshold values of regional SWI can thus contribute to the development of effective early warning and evacuation system of Sri Lanka. In the periods of application, these findings revealed that the good prediction practices for landslide predictions for real cases taken place. It is expected to continue the collection of rainfall data and landslide records to improve early warnings by deriving warning levels based on these SWI values and evaluating SWI index values for predicting cutting failures which unstable the slope stability as future developments.

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An Approach for Impact-Based Heavy Rainfall Warning, Based on the ECMWF Extreme Forecast Index and Level of Hazard Risk

M. M. P. Mendis

Abstract This study focuses on developed a methodology for impact-based heavy rainfall warning system in Sri Lanka. A warning matrix is developed as a basic tool of the impact-based warning system. The matrix relates to the level of risk to heavy rain hazards and likelihood of occurrence of imminent severe weather. Likelihood of extreme weather is determined by Total Precipitation Index (TPI) from European Centre for Medium-Range Weather Forecasts (ECMWF), Extreme Forecasts Index (EFI). The level of the risk is examined by based on vulnerability and hazards related to the heavy rain (mainly flood and landslides) in spatial grid scale. Levels of impact is calculated by using warning matrix. The severity of the warning is visualized using four color map-based system. This approach is tested through five case studies of typical disaster events occurred in Sri Lanka. Case study results provide comprehensive evidence for usefulness of hazards risk assessment in this study. Impact-based forecasts generated by all case studies are given equally good results and this information enables for disaster managers to take early action to prevent or minimize adverse effects of hazardous weather.

Keywords Impact-based forecast · Warning matrix · Extreme forecasts index (EFI)

1 Introduction

1.1 Background and Objectives

Sri Lanka is affected by various hazards, including weather related hazards such as cyclones, monsoonal rain, severe thunderstorm and subsequent floods and landslides. Hazards profile of Sri Lanka (DMC, 2012) is characterized by over 90 percent of the natural disasters that occur in Sri Lanka by hydro-meteorological origin. The most frequently occurring natural hazards are the floods and drought (MoDM, 2014; DMC, 2012). These occurs due to frequencies of monsoonal rains or failure of monsoonal rains respectively.

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On average over long term, Sri Lanka's sector-specific losses per year from natural disasters (flood, landslide, cyclone and drought) are estimated at US$380 million (GFDRR, 2016a). It is further mention that annual expected losses (AEL) are the highest for flood peril, with an AEL of US$240 million (GFDRR, 2016a). But Rogers et al. (2017) investigate that disaster losses significantly exceed this amount in a given year. A recent example of that, Global Climate Risk Index report (2019) estimated in terms of weather-related loss events in the 2017, it is ranking that Sri Lanka was second highest country on the Climate Risk Index which measures fatalities and economic losses occurring as a result of extreme weather (Eckstein et al., 2018).

The yearly monsoons, associated floods and landslides cause the most damages in Sri Lanka in terms of economic impact and human casualties (UNDRR, 2019). Sri Lanka comprehensive disaster management programme noted that marginal increase of figures on loss of life during the past five years partly due to the high intensity precipitation leading to flash floods (MoDM, 2014).

Landslides are seen to have a greater adverse economic impact in urban areas in the hill country with higher density of human settlements and infrastructure facilities. Heavy rainfall is considered as a triggering factor of landslides (Rathnayake & Herath, 2005), but significantly enhance the landslides potential due to the geological and topographical characteristics of the landscape, poor land utilization practices such as unplanned development and settlements together with harmfully extensive agriculture (Jayasinghe et al., 2017; MoDM, 2014; Perera et al., 2018).

Extreme variability of rainfall is already defining as a feature of Sri Lanka's climate. Future climate projections indicate an increasing rainfall trend in the wet zone and a decreasing rainfall trend in the dry zone in Sri Lanka (Darshika et al., 2018; Naveendrakumar et al., 2018). It is explicate that, the risks associated with water related hazards are likely to increase in future.

As such, the role of the National Meteorological and Hydrological Services (NMHSs) is crucial and important, in order to mitigate the damages generated by the disasters caused by hazardous meteorological phenomena (MoDM, 2014). It is a priority issue to detect hazardous meteorological phenomena which may create massive damages and disseminate highly accurate forecasts/warnings to the public more appropriately and promptly before the risk of disasters further escalate (WMO, 2012; Wilkinson et al., 2018; Coughlan et al., 2015). To overcome these challengers many NMHSs are moving towards a Multi-hazard Impact-based Forecast and Warning Services approach that translates meteorological and hydrological hazards into sector and location-specific impacts and the development of responses to mitigate those impacts (Neal et al., 2014; Barrett & Tokar, 2018; Casteel, 2016).

In the Sri Lanka context, weather forecasting at present in the Department of Meteorology (DoM) is performed mainly subjective techniques with numerical weather products used as guidance. As in most countries, Sri Lanka bases its warning system primarily on meteorological thresholds. Each warning level includes a summary of recommended actions to be taken when the warning is issued. These actions are usually quite general and do not provide specific guidance for a particular circumstance. The forecaster does not usually consider the vulnerability and exposure of the population to the hazard.

Introduction of multi-hazard impact-based forecast and warning services should be viewed as a central part of the effort to modernize NMHSs. This requires a significant change in NMHSs' operations, responsibilities, training and partnerships with other national and international actors (GFDRR, 2016b; Fabio et al., 2018; WMO-No., 1082, 2012). Therefore, following Impact Based Warning (IBW) framework developed as an initial approach for impact-based warning in Sri Lanka. Basic objective of this provides the Information of risks associated with natural hazards and its impacts to disaster managers and related agencies well in advance to take early actions to prevent or minimize adverse effects of hazardous weather.

2 Materials and Methods

2.1 Development of Framework

The WMO guidelines on Multi-hazard Impact-based Forecast and Warning Services (WMO-No., 1150, 2015) define three forecasting paradigms: (1) weather forecasts and warnings (which include information about the hazard only), (2) impact-based forecasts and warnings (which include information about the hazard and vulnerability to that hazard) and (3) impact forecasts and warnings (which include information about the hazard, vulnerability and exposure).

According to WMO guidelines the fundamental distinction between a general weather warning and an impact-based warning is the inclusion of vulnerability of people, livelihood and property with consideration of the hydro-meteorological hazard. That is the impact of the weather drives, the messaging rather than weather itself. This requires the capacity to predict the onset of specific meteorological and hydrological hazards in advance. Also it is required to communicate and inform to society in order to understand the threats and be able take appropriate mitigating actions (GFDRR, 2016b; Rochelle et al., 2018).

The early warning checklist developed by the International Network for Multi-Hazard Early Warning System (IN-MHEWS) has mentioned that four elements of efficient, people-centered early warning systems: (1) disaster risk knowledge based on the systematic collection of data and disaster risk assessments, (2) detection, monitoring, analysis and forecasting of the hazards and possible consequences, (3) dissemination and communication, by an official source, of authoritative, timely, accurate and actionable warnings and associated information on likelihood and impact, and (4) preparedness at all levels to respond to the warnings received (WMO, 2018).

Therefore, the warning services lie at the core of an early warning system. Hazard(s) information (monitoring), multi risk analysis and warnings are major component of the effective warning services. Based on that as a first step, fundamental framework was developed (Fig. 1) by considering with country specific capacity of predicting the extreme weather events, ability of physical and social vulnerability and risk assessment to support the quantification of impacts for early action. This

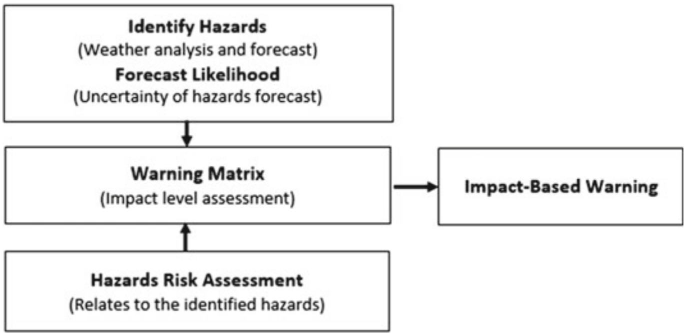

Fig. 1 Basic framework for impact-based weather warning is used in this study

study was carrying out by according to this framework and each component of the framework are described in the following sub sections.

2.2 *Identify Extreme Events/Hazards and Forecast Likelihood*

Weather forecasting is inherently uncertain for a variety of reasons. But, probabilistic weather forecasts attempt to characterize and quantify this inherent prediction uncertainty. Probabilistic forecasts potentially provide additional value over deterministic (or categorical) forecasts and aid to improve decision making (Clemens et al., 2017; Neal et al., 2014). Probabilistic forecast often based on Ensemble Prediction Systems (EPSs). EPSs aim to take account of uncertainty in weather forecasts by providing a range of forecast scenarios (Mingkeng et al., 2012; Atge, 1999; Legg & Mylne, 2004).

The European Center for Medium–Range Weather Forecasts (ECMWF) Ensemble Prediction System consists of one control forecast starting from the best guess initial conditions, and 50 members starting from slightly perturbed initial conditions (Neal et al., 2014). According to ECMWF user guide, they have developed an Extreme Forecast Index (EFI) for alert the forecasters to anomalous or extreme events using their own ensemble prediction systems.

Several studies found that EFI as a tool to provide forecasters with general guidance on potential extreme events based on information from the Ensemble Prediction System (Neal et al., 2014; Tsonevsky et al., 2018; Petroliagis & Pinson, 2012). Considering with the extreme rainfall prediction by EFI, many researches shows that the EFI is an effective indicator for extreme heavy rainfall events (Dong, 2018; Lavers et al., 2017; Tsonevsky et al., 2018). According to the ECMWF EFI assessment by Lavers et al., (2017), the precipitation EFI is more skillful throughout the medium range in the tropics, where extreme precipitation is predominantly linked with convection. Sri Lanka is a small island located near the equator in the Indian

Table 1 The likelihood scale used in this study based on ECMWF EFI

Term	EFI value	Likelihood category
Very likely	>0.6	4
Likely	0.5–0.6	3
About as likely as not	0.4–0.5	2
Unlikely	0.2–0.4	1
Very unlikely	<0.2	0

Ocean and extreme precipitation mostly link with deep convection. Therefore, EFI field of Total Precipitation Index (TPI) from ECMWF was selected in this study to capture the extreme heavy rain events at 72–24 h in advance.

In this study likelihood of forecast refers to the chance of occurring of severe weather according to the TPI value. The TPI ranks the departure between the forecast and the model climate between −1 (forecast given 100% probability that record low values will be reached) and +1 (record-breaking high values).

In the current operational system of every TPI field is based on forecast range of 24 h or longer. Since June 2012, ECMWF generate there are 41 time steps of TPI forecast data from two initial time steps (00UTC and 12UTC) per day (user guide to ECMWF, 2013). TPI parameter is valid for an accumulated value of the time period. The 24 h accumulation of negative EFI for precipitation does not make sense, because in most of the places a dry day is not considered as an extreme. But user guide to ECMWF (2013) mention that, the accumulation of negative EFI of TPI over longer periods does make sense. It gives the risk of dry weather for a relatively prolonged period of time. ECMWF MARS catalogue was used to get TPI data (https://apps.ecmwf.int/mars-catalogue) and highest spatial resolution of TPI is available at grid resolution of 0.125° × 0.125° (Latitude × Longitude). According to the framework of this study, TPI values categorize in to five categories and terms used by describe these categories based on calibrated language describe by Michael et al. (2011). The likelihood scale used in this study based on ECMWF EFI values are presented in Table 1.

2.3 *Hazards Risk Assessment*

Hazards risk knowledge is a one of the key element of successful early warning system. According to WMO guideline (WMO-No., 1150, 2015), risk is defined as the probability and magnitude of harm attendant on human beings, and their livelihoods and assets because of their exposure and vulnerability to a hazard. Intergovernmental Panel on Climate Change (IPCC) Fifth Assessment Report (AR5) in 2014 also refer that, risk is often represented as probability of occurrence of hazardous events or trends multiplied by the impacts if these events or trends occur. It is further mention that risk is results from the interaction of vulnerability, exposure, and hazard.

Therefore risk can be mathematically express as:

$$Risk = f\,(Vulnerability, Exposure, Hazards) \tag{1}$$

Several methods have been proposed to measure vulnerability from a comprehensive and multidisciplinary perspective (WMO-No., 1150, 2015; Cardona et al., 2012; Oppenheimer et al., 2014; Schneider et al., 2007). In some cases composite indices or indicators intend to capture favorable conditions for direct physical impacts—such as exposure and susceptibility—as well as indirect or intangible impacts of hazard events—such as socio-ecological fragilities or lack of resilience (Cardona et al., 2012). Also in the field of disaster risk management and climate change adaptation, risk identification and vulnerability assessment are undertaken in different phases: before, during, and after the disasters.

Primary objective of the impact-based forecast system is reduction of risk and vulnerability before occurring a disaster. It is important that ex-post study of weather related hazards in forecasts areas. Country-specific information such as topography, flood and landslide hazard maps, population demographics and geo-located critical infrastructure and other vulnerability and exposures are aid to rapidly identify populations at risk, exposed assets, physical and social vulnerabilities and to support the quantification of impacts for early action (Rochelle et al., 2018).

Vulnerability is defined by WMO guideline (WMO-No., 1150, 2015) as "susceptibility of exposed elements, such as human beings and their livelihoods and property, to suffer adverse effects when affected by a hazard". Vulnerability assessment of this study is based on the WMO definition. Therefore, considering with data availability at required resolution, vulnerability is taken in to function of exposure and sensitivity. The dimensions of vulnerability will consider only social and structural dimensions.

$$Vulnerability = f\,(Exposure, Sensitivity) \tag{2}$$

Thus, finally risk is considered by function of vulnerability and specific hazards.

$$Risk = f\,(Vulnerability, Hazards) \tag{3}$$

According to WMO guideline (WMO-No., 1150, 2015), exposure refers to who and what may be affected in an area in which hazardous events may occur. Sensitivity of the community or system to the hazard, relates to the system characteristics due to social or institutional factors which influence the likelihood of being harmed. Hazard is defined as a hydro-meteorological-based, geophysical or human-induced element that poses a level of threat to life, property or the environment.

The disaster risk of heavy rain was assessed for entire region in Sri Lanka. Heavy rains induced disasters, only flood and landslide were considered as major hazards of the risk assessment. Commonly used quantitative approach to assess vulnerability is the construction of a vulnerability index based on specific sets of indicators or combinations of indicators (Cardona et al., 2012; Oppenheimer et al., 2014; Schneider et al., 2007). Indicators used for calculation of vulnerability components and risk,

Table 2 Indicators used for the vulnerability and risk assessment and assigned weight for each indicators

Component	Indicators	Functional Relationship	Spatial resolution	Data sources	Weight
Exposure	Total population	+	District secretariat division (DSD) level	Department of census and statistics (2012, -census)	0.58
	Number of houses	+			0.31
	Number of schools	+	District level	School census report-2017	0.11
Sensitivity	Poverty head count index (PHCI)	+	District level	Department of census and statistics (2012-census)	0.50
	Literacy rate	–			0.50
Hazard	Flood	+	District level	Disaster management centre (Disaster data-1974 to 2017)	0.50
	Landslide				0.50

their functional relationship, spatial resolution of data and data sources are shown in Table 2.

All the indicators were normalized by rescaling (min–max) normalization method (OECD, 2008; Zurovec et al., 2017). Normalized indicator of the respective element was weighted based on their degree of influence on vulnerability and risk. Weights of the exposure indicators was assessed by using Analytic Hierarchy Process (AHP) method (Satty, 1980; Saaty, 2008; Chakraborty & Joshi, 2016). The AHP is used as a Multi-Criteria Decision-Making (MCDM) tool develops by Saaty (1980). Triggering factor of both hazard (flood and landslide) is heavy rainfall and both hazards triggers and increases the probability of secondary hazard (Gill & Malamud, 2014). Therefore, Equal Weight (EW) method apply to each indicator of respective elements to assign the weight for hazards assessment. Poverty Head Count Index (PHCI) and Literacy rate are also considered as same level on their degree of influence on sensitivity assessment. The assigned weights for each indicators are shown in Table 2.

Spatial resolution in some of exposure indicators (population and houses) differ than others. Therefore, after assign the weights for all indicators, each element was converted in to raster data with grid resolution of 0.125° × 0.125° (Latitude × Longitude) by using ArcGIS 10.3.1 software. The spatial resolution of raster data was selected, according to the available maximum grid resolution of ECMWF EFI data.

The normalized weighted values of the each indicators were added to generate the three sub-indices of risk (exposure, sensitivity, and hazard) by applying the following formula (Gbetibouo et al., 2010; Zurovec et al., 2017).

$$Sub\ index = \sum_{i=1}^{n} w_i \left(X_{ij} - \overline{X}_i\right)/S_i i = 1, \ldots, n; j = 1, \ldots, m \quad (4)$$

where w is the weight, i is the indicator, X is normalized indicator value, j is a specific grid, $\bar{X}$ is mean of normalized indicator value, and S is the standard deviation. Using three sub-indexes overall hazards risk index for heavy rain disasters was compute by applying the following formula:

$$Risk = Exposure + Sensitivity + Hazard \quad (5)$$

As a final step, hazards risk indices were classified in to 5 categories as high (5) to low (1) using frequency distribution and field experience of floods and landslides hazards. These hazards risk fields are static fields representing heavy rainfall hazards risk for each grid box in country.

2.4 Impact Forecasts

WMO highlight that one of the most important factors to be considered in making assessments of hazards and risks is the purpose for which the assessment is being made, including the potential users of the assessment (WMO/TD-995, 2006). According to framework developed in this study, warnings are issued when severe weather has the potential to bring impacts in Sri Lanka. Warnings are based on a combination of the severity of potential impacts and the likelihood of those impacts occurring. Aim of that provides “early briefings” to government decision-makers, special users and agencies well in advance of releasing public warnings so that the agencies have enough time to react and prepare. In this context following warning matrix (Fig. 2) is used to determine the appropriate warning levels (green, yellow, amber and red) to generate the heavy rainfall warning. Likelihood of hazard is an

Likelihood Category \ Risk Category	1	2	3	4	5
4	4	8	12	16	20
3	3	6	9	12	15
2	2	4	6	8	10
1	1	2	3	4	5
0	0	0	0	0	0

Warning level	Level of impact	Warning Description
0	0 – 2	No Impact
1	3 – 6	Low Impact
2	8 – 10	Moderate Impact
3	12 – 20	High impact

Fig. 2 Warning matrix (left) and final warning levels (right) is determined according to the different impact score categories in the matrix

output of Extreme Forecast Index (EFI) and the expect impact is estimated based on potential level of specific hazards risk.

According the warning score matrix, level of the impact could be expressed mathematically as follows:

$$Level\ of\ Impact = Likelihood \times level\ of\ hazards\ risk \tag{6}$$

The warning matrix shows that hazards risk is increases from left to right, while the likelihood of severe weather is increases from bottom to top. Impact score was calculated by multiply with these two categories. Level of warning ranging based on quantitative assessment of impact scores. It is considered that, WMO guideline (WMO-No., 1150, 2015) and international experience relating to the impact-based warning systems (GFDRR, 2016b; Neal et al., 2014; Rebecca & Joanne, 2019). An important aspect of the impact assessment is that the same weather may have different levels of warning in different parts of the Sri Lanka.

Geographical Information System (GIS) is used as a tool for analysis of EFI data and hazards risk. Impact-based warning was generated into a convenient grid (0.125° × 0.125°) and four colors represent the warning levels of each grid boxes.

3 Results and Discussion

3.1 Hazards Risk Assessment

Risk Assessment is a key factor of this impact-based warning system. Spatial resolution of the disaster risk areas was measured in 0.125° × 0.125° (Latitude × Longitude) grid scales for the entire region of Sri Lanka. The results are shown in Fig. 3.

The central highlands areas in Sri Lanka contain many complex topographical features such as ridge, peaks, plateaus, basins, valleys and escarpments. These areas are shows highest hazards risk levels in the country. Among that, risk level is high in the western slope of central mountainous areas where the heavy rains mainly occurred during southwest monsoon period. According to this assessment Nuwara Eliya and Rathnapura districts are the most vulnerable district in Sri Lanka to extreme rainfall where the other all sub-indexes are high. Moderate exposure at some grids and high sensitivity created that significant vulnerability differences in the Colombo district.

Vulnerability index are high in the Batticaloa, Trincomalee and Kilinochchi districts due to high sensitivity in those district. Therefore hazards risk levels are high in those districts (Fig. 3). These districts are coastal plain and more prone to flood hazards due to extreme weather events such as heavy rain from northeast monsoon, cyclones, depressions or low pressure systems developed in the Bay of Bengal.

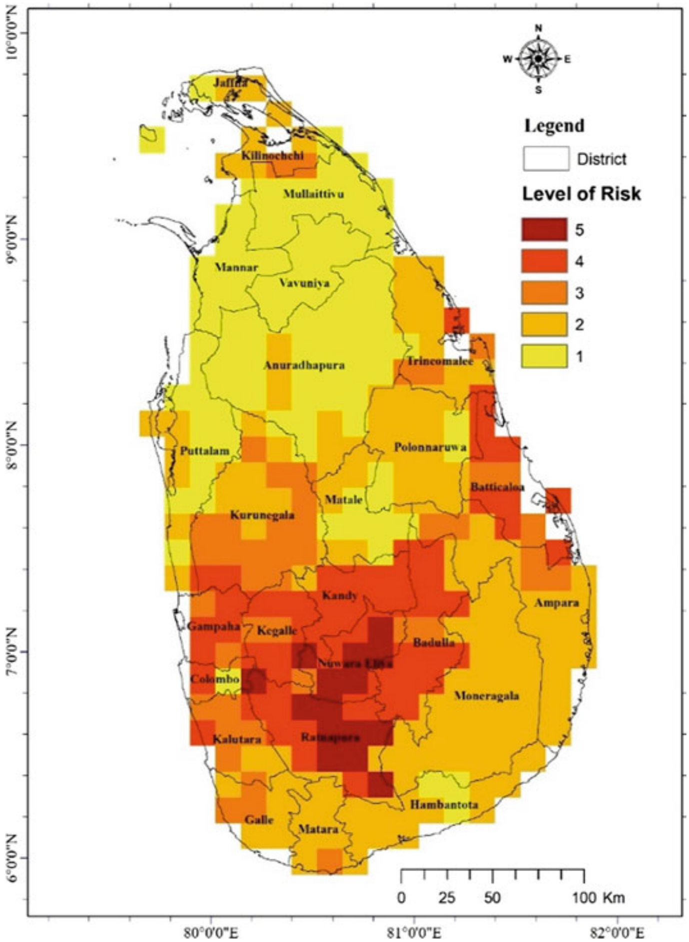

Fig. 3 Spatial distribution of hazards risk index for heavy rain in Sri Lanka, measured by additive of exposure, sensitivity, and heavy rain hazards indices. Each grid box (0.125° × 0.125°) categorizes as 1 (low) to 5 (high) hazards risk levels based on frequency distribution and hazards experiences

3.2 Evaluation of Case Study Results

This impact-based warning approach was tested through five case studies of typical disaster events occurred in Sri Lanka: (1) 15th November 2015, (2) 15th May 2016, (3) 25th May 2017, (4) 20th May 2018 and (5) 06th October 2018. Generated impact-based forecasts of heavy rainfall events were qualitatively evaluated with reported disaster data in each districts.

TPI from ECMWF EFI was well captured each extreme event at 48–24 h in advance. Figure 4 shows the likelihood of extreme precipitation forecasts of 48 h before (upper panel) and 24 h before (middle panel) the each events based each day

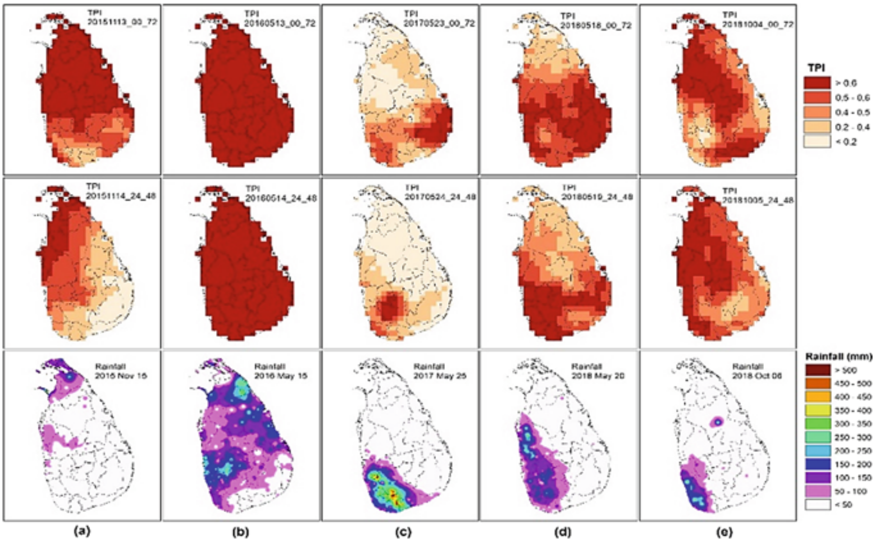

Fig. 4 Total precipitation index (TPI) from ECMWF EFI at 00–72 h forecast (upper) of 48 h before and 24–48 h forecast (middle) of 24 h before the events based on 00 h analysis. Lower panel shows observed rainfall at 24 h period of each events. Columns are denote at each heavy rainfall events. (**a**) 15th November 2015, (**b**) 15th May 2016, (**c**) 25th May 2017, (**d**) 20th May 2018 and (**e**) 06th October 2018

00hour analysis. Compare with observed 24 h rainfall (lower panel) of each events and TPI values indicate that, likelihood category of likely (TPI value is 0.5–0.6) and very likely (TPI > 0.6) levels provided good signals for imminent extreme rainfall events over areas in 48 h and 24 h in advance. It is further shows that TPI provided more reliable forecasts at 24 h in advance.

3.2.1 Heavy Rainfall Event of 15th November 2015

Impact-based forecast of 15th November 2015 shows high impact level in the Jaffna and Killinochchi districts (Fig. 5(a)). Meanwhile districts in the Central, Western and Northwestern are shown moderate and high impact due to the high likelihood (0.5–0.6) values in the region. Due to formation of depressions in Bay of Bengal, extremely heavy rainfall was reported within 24 h on 15th November in the Northern Province (Fig. 5(a)) and local flood events were reported in Jaffna and Killinochci districts. According to daily situation report (17th Nov. 2015) of Disaster management Centre (DMC) Sri Lanka, around 52,558 peoples were affected by local floods.

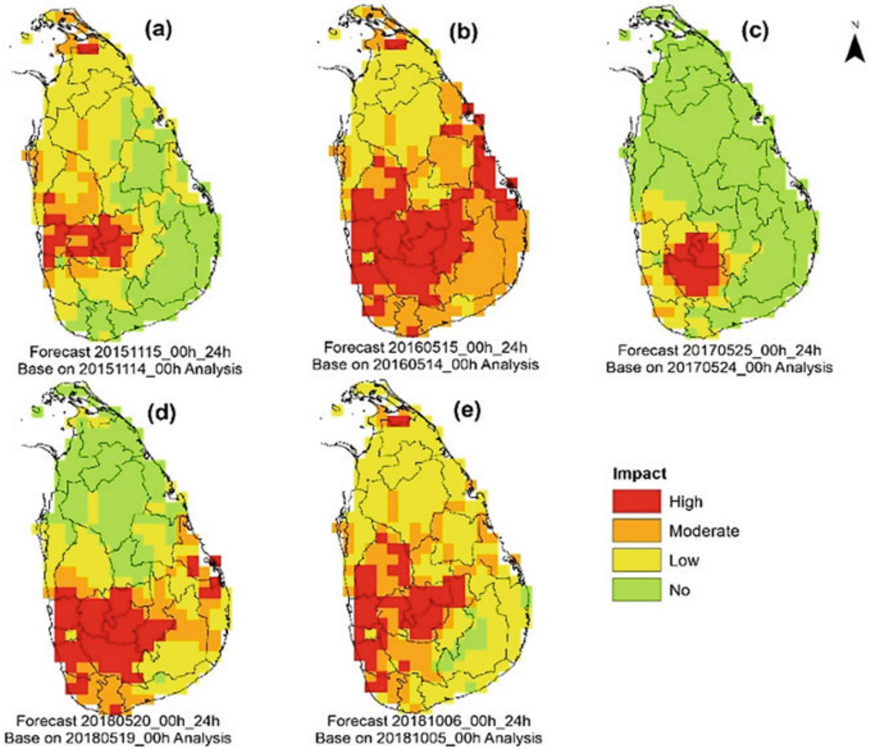

Fig. 5 Heavy rain impact-based forecast for 24 h period. (**a**) 15th November 2015, (**b**) 15th May 2016, (**c**) 25th May 2017, (**d**) 20th May 2018 and (**e**) 06th October 2018

3.2.2 Heavy Rainfall Event of 15th May 2016

During 14th–18th May 2016, a low pressure system was developed in the vicinity of Sri Lanka. The system was moved along the east coast and gradually developed into a severe tropical cyclone 'ROANU" causing widespread flooding and landslides in 23 districts out of 25 districts in the country and destroyed properties and submerged entire villages. Majority was due to the landslide at Aranayake in Kegalle district, which devastated three villages (Flood and landslide situation report of May, 2016). These areas are well captured as high impact areas by impact-based forecasts generated before 48 h (not shown here) and 24 h (Fig. 5(b)) of the event.

3.2.3 Heavy Rainfall Events of 25th May 2017 and 20th May 2018

The southwest monsoon typically peaks during late May to the beginning of June in Sri Lanka. During this period usually received heavy rain in the Southwestern part of the country. Heavy rainfall events of 25th May 2017 and 20th May 2018 are examples for that.

On 25th May 2017 heavy rain was concentrated in to smaller area of Southwestern part (Fig. 4(c)). ECMWF EFI was well captured in this area (TPI > 0.6) and hazards impact is predicted as high on those areas (Fig. 5(c)). But spatial evaluation of impact forecast results with effected areas are shown (figures are not shown here) that impact-based forecast system not well predicted by Gampaha, Galle, Matara and Kalutara districts as high effected areas where the most effected districts according to Flood and landslide situation report of May, (2017). It is indicated that this impact-based forecast system highly depends on the forecasts likelihood of extreme weather. These coastal district mostly effected by river floods and that occurs when heavy rain falls in the upper catchments of the river basins. But, overall forecast can be drawn the attention of disaster managers for the potential threat of extreme weather at 24 h in advance.

In the year 2018 heavy rain was occurred during pre-southwest monsoon on 19th May and caused severe damages in larger areas of the country due to flash floods. Sabaragamuwa, Central, Southern, Northwestern and Western Provinces were severely affected by the floods situation (Daily situation report of May, 2018). The heavy rain was received on 19th early morning. But TPI forecast generated at 00–72 h based on 00 h analysis 18th May 2018 situation was overestimated (Fig. 4(d)-upper). With these uncertainty of the forecast likelihood, spatial assessment of the results indicate that most affected areas well predicted by impact-based forecast system (Fig. 5(d)).

3.2.4 Heavy Rainfall Event of 06th October 2018

Period of October to November is second inter-monsoon season in Sri Lanka. Convective activities with widespread evening thunderstorm are prominent in this period. Under the influence of a low level atmospheric disturbance, convective activity was enhanced on 06th October 2016 particularly in Western part of the country and 200–300 mm rainfall were reported at some places in Galle and Kalutara districts (Fig. 4(e)).

Prediction of extreme rainfall by ECMWF EFI was highly uncertain in this event (Fig. 4(e)). TPI value was greater than 0.6 over most of the areas in the country except in Eastern and Southeastern areas. But extreme rainfalls were occurred in Southwestern part and some isolated places in the Anuradhapura district. As a result of heavy rain, 74,778 persons were affected by flash floods and cutting failures in Kalutara, Gampaha, Colombo, Galle and Kandy districts (Flood and landslide situation report of October, 2018). Those areas predicted as high impact areas by impact based forecast system (Fig. 5(e)). Central region of the country was predicted as a high impact area in the forecast, but statistics of reported disaster data indicate that only Kandy district was affected by heavy rain. However, overall forecast provided good guidance to disaster managers and forecasters at 24 h in advance.

4 Conclusion

The case studies illustrate that all extreme events were well captured by EFI at 48–24 h in advance with spatial uncertainties. However, ECMWF EFI can be used as an alarm for the extreme weather events over any area without defining different space and/or time-dependent thresholds.

The severity of the impacts prediction of a disaster is strongly depends on the level of hazards risk. Assessment of vulnerability levels for heavy rain in Sri Lanka is a challenge due to lack of adequate data in required resolution and complexity of defining the vulnerability. Vulnerability studies shows that the highest sensitivity does not always lead to highest disaster vulnerability. The areas of less number of hazards does not always necessarily result in the lowest hazards risk since the areas have different levels of exposure. The case study results provide comprehensive evidence for usefulness of hazards risk assessment in this study. Impact-based forecasts generated by all case studies were given equally good forecast results and this information enables to disaster managers to take early action to prevent or minimize adverse effects of hazardous weather. Most flooding in Sri Lanka occurs when heavy rain falls in the upper catchments of the major river basins. This allows the warning authorities a long lead-time to estimating the likelihood and level of flooding in downstream.

Visualization of meteorological warnings in graphical way is an important part of impact-based warning system. Generally, first response of the warning goes to colors and then each of the "grid cells". In this study grid cell is not representing any administrative boundaries. The advantage of matching administrative boundaries is the presence of public officials in each of the "grid cells", which have responsibility for the response to a warning. To make finer scale warnings such as district secretariat division (DSD) level, high resolution (ideally 1 km) and more reliable numerical weather prediction guidance are required. Identifying the exact impacted administrative areas of hazards is a challenge for this warning system but, it can be used government decision-makers, special users and agencies as an "early briefing" so that the agencies have enough time to react and prepare.

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An Agro-Met Advisory System to Reduce the Climate Change Risks and Enhance Disaster Risk Resilience of Farmers in Dry and Intermediate Zones of Sri Lanka

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Abstract A study was conducted to assess the status of the present agro-meteorology information and advisory system including gaps to disseminate agro-met advisories to the interested parties, based on which to propose a suitable agro-meteorology advisories and information system to facilitate field level decision making among vulnerable groups. The study comprised of both survey and interview-based approaches covering Kurunegala and Anuradhapura districts. It was found that there were substantial inefficiencies in the present system run by the Department of Meteorology (DoM) and Department of Agriculture (DoA) such as time-consuming and too general nature, while the lack of awareness among stakeholders. The proposed agro-met advisory information system has seasonal forecast and 3, 10 and 30 day forecasts which will be collaboratively prepared by the DoM and DoA. The DoA should also maintain and run the advisory information system. Instead of present top to bottom approach, these advisories will be disseminated regularly and simultaneously to the ground level, using a variety of ICT tools under two mechanisms. In one mechanism advisory information will be sent to the tank-based farmer societies enabling them to make informed decisions and these will be monitored and supported

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by technical experts, while in the other, individual groups/ persons can access the information upon registration. Moreover, the new system facilitates a two-way real time information and data management system.

Keywords Agro-met advisory system · Dry zone · Intermediate zone · Sri lanka

1 Introduction

1.1 Agriculture in Sri Lanka

Sri Lanka is situated in the tropics between 5° 55′ and 9° 51′ North latitude and between 79° 42′ and 81° 53′ East longitude. The climate is characterized as tropical and the mean annual temperature varies from 27 °C in the coastal lowlands to 16 °C in the highlands. The mean annual rainfall varies from under 900 mm in the driest areas to over 5000 mm in the wettest areas. There are several climatic zones in Sri Lanka as based on the rainfall namely 'wet zone', 'intermediate zone' and the 'dry zone'. Based on the rainfall and the rainfall pattern, country has two distinct climatic seasons called *Maha* (wet) and *Yala* (dry) season. The main climatic season is the *Maha* season which lasts between October–March. The highest potential for rice productivity is in the low country dry and intermediate zones (Dhanapala, 2000).

The agricultural sector in Sri Lanka serves as the major means of livelihood in the country by providing direct employment to 25.5% of the labour force, although its contribution to the Gross Domestic Product (GDP) has declined from 46% in 1950 to 7.9% in 2018 (CBSL, 2020). Rice is the dominant crop occupying 34% (0.77 million ha) of the total cultivated land in Sri Lanka, with approximately 1.8 million people engaged in paddy cultivation. On average, 560,000 ha are cultivated with paddy during the *Maha* season and 310,000 ha during the *Yala* season, which add up to total extent of sown area of about 870,000 ha annually (Department of Agriculture, 2020).

1.2 Climate Change and Agriculture

Climate change represents extensive and long-lasting alterations to the natural environment and the ecosystem caused mainly by the emission of greenhouse gases. In the recent past, Sri Lanka has experienced extreme weather events such as floods, landslides and droughts, which are predominantly caused by rainfall variability. Agriculture is one of the sectors that has been adversely affected by the impacts of climate change. In Sri Lanka, the farming districts in the dry zone are more vulnerable to climate change than the rest of the country as they are affected by other factors too like land degradation, water scarcity, and heavy reliance on primary agriculture (Eriyagama et al., 2010). As agricultural activities are predominantly dependent on weather conditions, early warning weather forecasts are essential to mitigate any negative impacts and reduce the risk in agriculture (Reddy et al., 2014) to pave the way for increasing crop production. Because the impact of climate change on agriculture depends upon variations in the local climate rather than global climate, agriculture should be location and crop specific to ensure a good yield as demanded by farmers (Bendapudi et al., 2019). Agro-met advisories provide crucial information about agriculture and the climate (Timilsina et al., 2019) that could be used in decision making on agronomic practices (Nesheim et al., 2017; Reddy et al., 2014).

1.3 Importance of Weather Information for Disaster Risk Resilience

In the context of climate change, access to accurate weather forecasts, advisories and early warnings are of paramount importance to ensure better decision-making at all levels of agricultural activities as that will enable the community to better manage any existing climatic risks while improving the disaster resilience.

The local authorities, including district and divisional administration and line agencies in Sri Lanka are at present rather ineffective at efficient generation and dissemination of agro-met advisories and early warnings. The reasons are, (a) lack of capacity in the respective agencies to develop location-specific information bulletins, (b) gaps in the information dissemination channels, (c) insufficient knowledge among users to access and interpret the early warnings in the climate and weather advisories and make informed decisions, and (d) poorly coordinated service delivery, such as extension services, insurance, financial market and allied services at the local level in response to the forecasts/advisories. Against this background, the aim of this study is to establish an effective and efficient integrated weather information system for farmers and local decision makers in the rain-fed dry and intermediate zones to enhance their disaster resilience.

2 Methodology

2.1 Assessment of Needs and Demand for Weather Related Information

The needs assessment, i.e., estimating the demand for weather advisories, was aimed at assessing the extent to which agro-met advisories (AMAs) are required by extension officers, farmers and other grassroots level decision makers. In addition, the ease of current access and mode of access, preferred frequency and timing were evaluated. Meanwhile, the capacity of the receivers to interpret and apply the advisories in real situations and the support services required for that were also studied. In this context, the information pertaining to crop management were also considered. A series of interviews with extension officers were conducted using structured questionnaires, followed by focus group discussions (FGD) with officers and farmers, in Anuradhapura and, Kurunegala districts. One hundred and thirty-six government officers were interviewed in the survey, and two hundred and twenty one officers and farmers participated for the FGDs.

2.2 Evaluation of the Existing Weather and Agriculture Advisory System

A series of key informant interviews were conducted with responsible officers attached to the relevant agencies. This was followed by studying the relevant documents to gain familiarity with institutional policies, procedures and practices related to the generation and dissemination of weather advisories. Current process of agricultural and water management decision-making in the targeted areas, the institutions involved and their capacity, as well as the present dissemination path were also reviewed.

Assessments of the capacity of Agrarian Services Centres (ASCs) to act as local knowledge hubs and to interpret and co-develop methods were accomplished through site visits. The extent of support services required to adopt advisories at the farmer level was evaluated through compilation of the information followed by desk reviews.

2.3 Development of Solution Packages to Deliver Effective Weather and Agriculture Advisories to Farmers

A user-friendly system architecture to disseminate the climate, weather and agricultural advisories to target groups (farmers, local agencies) was designed and proposed by the researchers. The ease of access by farmers, efficiency, cost-effectiveness and sustainability were assessed with the target groups. Lastly, information nodes, channels and participatory co-development requirements of the advisory at the provincial/district and divisional level were scrutinized. Meanwhile, validation of the proposed solution package regarding its suitability for use by the respective stakeholder agencies and farmers was done through consultative workshops.

3 Results and Discussion

3.1 Assessment of Demand for Weather-Related Information from the Extension Officers and Farmers

3.1.1 Receipt and Usage of Agro-Met Advisories

The survey done with the extension officers found that only twenty-two percent of the officers have received the AmAs regularly. Nearly a half of the sample respondents (47%) indicated that the AmAs were delivered quite irregularly, while about a third of the respondents claimed they hardly ever received the AmAs. Almost all have not received 10-day weather forecasts. Most of the officers (83%) acknowledged the usefulness of such weather information, but 78% expressed concern about its accuracy. This was followed by 75, 70 and 67% of respondents voicing their concerns about the timeliness, accessibility and location specificity respectively, of the information (These are overlapping percentages). It was found that 52% of the respondent officers who received the AmAs used these in cultivation related decision making. The reasons cited by the respondents for not using the AmA (even when received) included inadequacy, less trust on its accuracy, delay in receiving it, and non-specificity. Most of the farmers had an awareness of the AmAs. However, since climatic information is not area-specific and there are doubts about its accuracy, farmers are reluctant to use it in decision making (even when they have received it). Television is the preferred source of information followed by radio.

3.1.2 Demand for Weather Information by Agronomic Practices

AmAs are needed during both *Yala* and *Maha* seasons. The officers desired more detailed AmAs that provided information on duration and intensity of rainfall, temperature, daylight hours and wind speed. They should be understandable, accurate, received at the right time, and delivered in a reliable manner. Further, majority of officers (59%) preferred to obtain short-range forecasts (1–3 days), followed by officers who preferred medium-range forecasts (up to 10 days). Forty-eight percent of officers preferred sub-seasonal (10–30 days) forecasts whereas 32% needed weather alerts. The most desired type of advisory was the crop-based one as mentioned by 79% of the officers. Most of the officers (62%) liked to receive weather forecasts through the Short Message Service (SMS), while a considerable percentage of respondents preferred to have the forecasts delivered through television, smartphone apps and IVR (Interactive Voice Response system).

3.1.3 Type of Climatic Information Needed by Farmers

The farmers mentioned that they required long term advisories to improve agriculture, advisories to minimize damages, and to get ready for future farming. Majority of farmers preferred to obtain medium range (up to 10 days) forecasts to be used for their cultivation.

3.2 Evaluation of the Existing Agro-Met Advisory System

3.2.1 Process Currently Followed by the Various Institutions Involved in Developing and Issuing Agro-Met Advisories

Four departments and two line ministries which are directly involved in the process were identified. They are Department of Meteorology (DoM), Department of Agriculture (DoA), Department of Agrarian Development (DAD), Department of Irrigation, Ministry of Agriculture, and Ministry of Mahaweli Development and Environment. Also, involved in the process are Mahaweli Authority of Sri Lanka at national level, Provincial Departments of Agriculture at provincial level, District Secretariats at district level and Agrarian Service Centers at divisional level.

3.2.2 Climate Services Provided by DoM

The DoM issues a series of forecasts including Short Range (1 to 3 days, updated 3 times per day), Medium Range (Graphical) direct from Numerical Weather Prediction for 9 days (updated daily) and. Long Range forecast for the following month. Additionally, three-month forecast updated at the beginning of every month and also for the four seasons, updated before the start of every season. The DoM issues seasonal forecasts of one month and three months and these advisories are used for planning and advisory preparation work by certain organizations including the DoA. All these forecasts prove useful for agriculture to make necessary decisions. Figure 1 depicts the present system for Agro-met advisory generation and dissemination.

3.2.3 The Generation of AmAs by the Department of Agriculture

The DoA functions under the Ministry of Agriculture (MoA). The following divisions of the DoA are involved in the process namely, Natural Resources Management Centre (NRMC) and National Agricultural Information and Communication Centre (NAICC) including the Farm Broadcasting services (FBS). Also, the Provincial Departments of Agriculture (PDoA) are engaged in the process.

Among the key responsibilities of the NRMC is to maintain the agro-meteorological observation network and to develop the AmAs. The NRMC issues

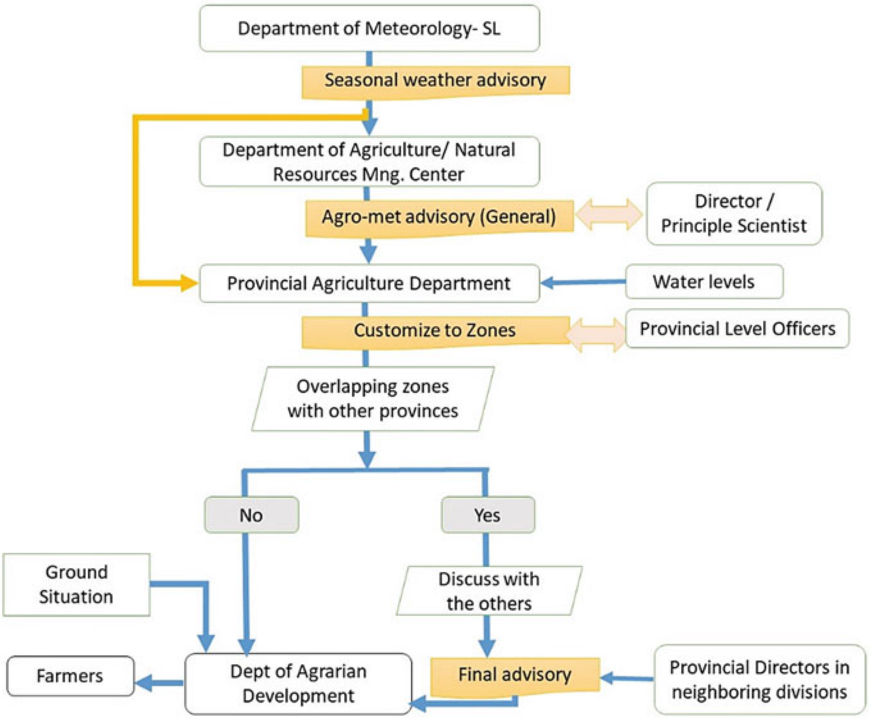

Fig. 1 The present agro-met advisory system

weather advisories based on the seasonal weather forecasts and medium-range weather forecasts if necessary. Seasonal weather forecasts are transformed into AmAs by appending other useful information (e.g., availability of water, etc.) and they are issued every month. Seasonal forecasts are issued to all officers and line agencies such as Irrigation Department (ID) Mahaweli Authority of Sri Lanka (MASL), Department of Agrarian Development (DAD), and Hector Kobbekaduwa Agrarian Research and Training Institute (HARTI).

The DOA and PDoA would send the AMAs to the Agriculture Instructors at the ASCs, either of provincial staff or central staff. However, dissemination of information to the next level and mainstreaming of weather information in cultivation decision meetings at the district level does not occur as expected. The mode of communication of AmAs is the email. 10-day weather forecasts are used for an emergency situation arises. SMS is sent to the users in local languages which frequently include English technical terminology.

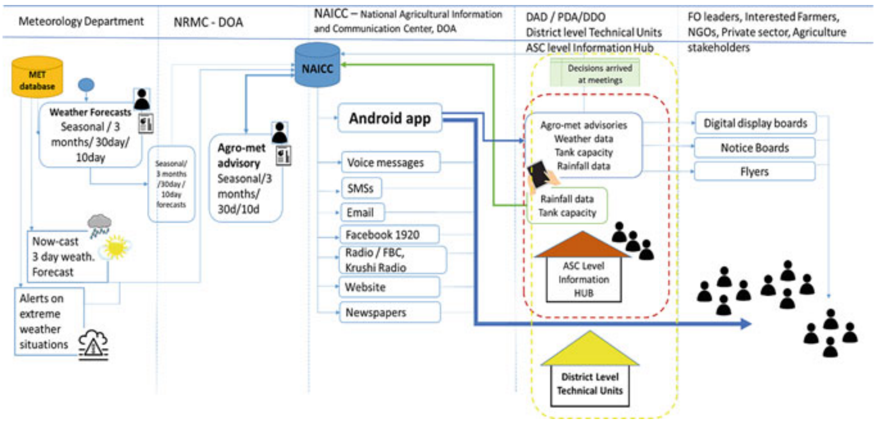

Fig. 2 A model to disseminate agro-met advisories

3.3 Development of a Model to Disseminate Agro-Met Advisories

3.3.1 Information System to Disseminate Agro-Met Advisories

Realizing the need for a well-integrated decision support system to disseminate agro-met advisories, the following model was developed (Fig. 2). This system enables effective collaboration and coordination among the various actors involved in agro-met advisory generation and dissemination. Special emphasis was given to improve the efficiency of the system through a more flattened structure.

Development and maintenance of the Agro-met Advisory Information System (AmAIS) has to be the responsibility of a government agency, preferably the DoA. The other agencies will access the AmAIS through the web interface. Field level Extension and Development officers will access the AmAs using tablets or mobile phones, preferably through a mobile application. Actual weather data such as rainfall and temperature collected from the field can be input to the AmAIS using the same application. Features available in mobile devices such as phone cameras and voice recordings can be easily used to input advisory related decisions made during stakeholder meetings to the system.

3.3.2 Use of Available ICTs

Farmers preferred to have precise and timely weather-based agricultural advisories as they allowed them to make informed decisions. However, receiving agro-met advisories will be influenced by the availability of ICTs among the target community, among other factors. In areas where Internet facilities are not available, traditional media such as radio, television, and display panels can be used in combination with

Table 1 Possible ICT tools that can be used to disseminate Agro-met advisories

Type of information	ICT tools used to disseminate information
Agro-met advisories for the season (3-month duration)	Website, android app, radio, newspaper, email, facebook 1920, voice messages, sms alerts, leaflets
Agro-met advisories 30-day/10-day	Website, android app, radio, newspaper, email, facebook 1920, voice messages, SMS alerts
Weather now-cast and location specific weather data	Android app, website
Alerts on extreme weather situations/disaster warnings	SMS, radio, voice messages, website, android app, email, facebook 1920
Agro-met advisories for the cascade/decisions made at the divisional information hub	Website, android app, voice messages, digital display boards, notice boards, SMSs

limited ICT services (Singh et al., 2009). Other conventional options include digital displays and notice boards kept at public places, in addition to leaflets and posters.

The proposed model needs to use user friendly approaches such as voice recordings, mobile applications, websites, and social media platforms in addition to the traditional media. Especially, the use of mobile devices to reach the field officers and farming communities will be emphasized.

Use of multiple methods to communicate agro-met advisories may strike one as redundant too ambitious, but such methods can 'facilitate greater awareness and interest among farmers' (Vedeld et al., 2020). The AmAIS needs to make use of all available ICT tools, from local radio channels to social media platforms to provide information to the end-users. Table 1 elaborates on the possible means of distributing these advisories to the target community.

3.3.3 Need for a Common ICT Platform

It is desirable to establish a single information system to access, produce, store and disseminate agro-met information by linking all the central and local government organizations involved in the process. There is no such system in place now, and all agro-meteorological information is passed from one organization to another using conventional communication facilities. For the successful performance of the AmAIS it is essential that all concerned institutions collaborate and coordinate at various stages in providing data, retrieving data, producing mass media messages and monitoring the process, using a single ICT platform. Other advantages of establishing a system include ease of monitoring the advisory generation process, and ability of local organizations to provide real-time feedback to the experts. The proposed AmAIS need to be coupled with other cultivation related information systems, enabling the users to access useful technical information together with agro-met advisories, leading to more meaningful decision making. For instance, there are other information systems developed by the DoA such as seasonal calendars, crop suitability index, fertilizer recommendations, and crop-water requirement calculation apps and so on, that can be linked to the agro-met advisories. Next, there is the possibility of incorporating the real-time weather updates received through the Online weather data monitoring system of the DoM into the AmAIS. This will enable the end-users to access all of the pertinent data sources through a single system. Accessing such information will also help the end-users to make better decisions relating to water management.

3.3.4 An Android Based Mobile Application

Field officers attached to the local information hubs play a key role in the proposed AmAIS as they are responsible for facilitating cascade level water management decision making. A mobile application that can be operated on a mobile phone or tablet will be a more practical and useful tool for these officers to retrieve the AmAs, and enter decision information into the system. An android application seems very promising due to the wide availability of android based devices in the country. A mobile application will prove quite useful for uploading field-level data, namely decisions arrived at the ASC level information hub, actual rainfall figures, temperature, etc. to the system.

3.3.5 System Architecture of the AmAIS

The system architecture proposed for the AmAIS is given in Fig. 3. The proposed system will enable collaboration among several organizations such as DoM, DoA, PDoA, and DAD. The two essential functions of AmAIS will be the management of agro-met advisories and dissemination of such information to interested parties. Features of the proposed AmAIS are explained in the next section.

3.3.6 Problems and Challenges

The foreseeable challenges in implementing the AmAIS are many. Technical issues relating to poor literacy, low capacity to interpret the advisories, poor access to ICTs, inadequate ICT skills, language barriers, and poor network coverage in rural areas may hinder the successful adoption of the AmAIS among the farming community. These issues need to be addressed by providing training, awareness creation, use of multiple sources to disseminate information, and free distribution of ICT devices for conducting pilot testing. These are some of the possible mechanisms that could be adopted. Proper coordination between all of the implementing agencies is crucial to ensure good performance, as there are several government bodies involved in the process.

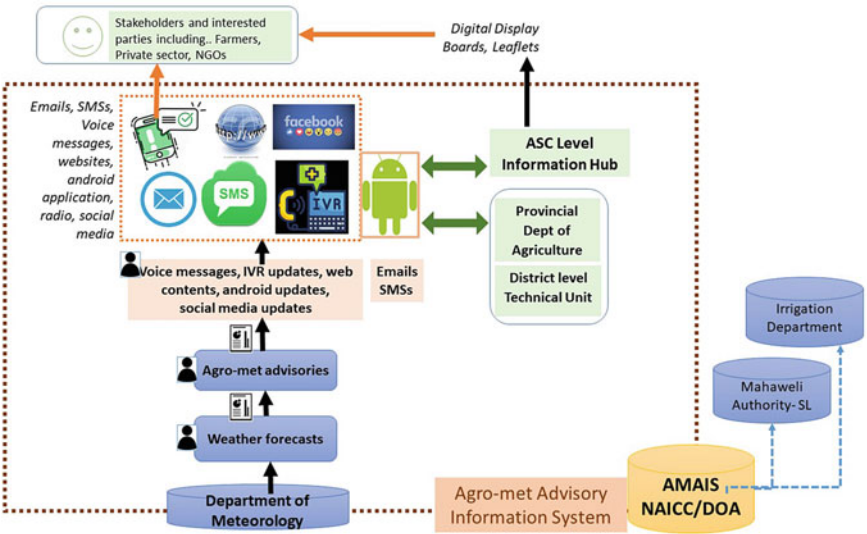

Fig. 3 The system architecture for the proposed AmAIS

4 Summary

The present system of dissemination of agro-met advisories and early warnings in Sri Lanka possesses a number of inefficiencies such as gaps in the information dissemination channels, poor coordination, not receiving weather information in a timely manner, low usability due to the too general nature of such information, and difficulty in understanding of technical information by the end-users. However, as found by the study, there is a demand for location-specific and timely weather information. The end-users were enthusiastic to receive the weather information and early warnings using the latest ICT tools. In this study, attempts were made to establish an integrated weather information system for farmers and local decision-makers in the rain-fed dry zone and intermediate zone to enhance disaster resilience.

The views expressed in this chapter are those of the authors and do not necessarily reflect the views of the United Nations Development Programme.

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Spatial and Temporal Variability of Lightning Activity in Sri Lanka

I. M. Shiromani Priyanthika Jayawardena and Antti Mäkelä

Abstract Sri Lanka is one of the major lightning prone countries in the South Asia and Lightning kills in Sri Lanka about 50 people each year. The spatial and temporal variability of lightning activity in Sri Lanka from 2015 to 2018 has been studied using GLD360 lightning location data in 2 km × 2 km grid. Vaisala GLD360 lightning location data was provided under the collaborative project "Severe Storm Warning Services for Sri Lanka (SSWSS)" with the Finnish Meteorological Institute and Vaisala Inc. These data have been examined for depicting the annual, seasonal, and spatial distribution of the lightning activity. The study indicates that the annual mean lightning rate for the period from 2015 to 2018 is maximum in an area along the western foothills of central hills and decreases at higher elevation of central hills; this is linked with the convective activity due to solar heating of land, large-scale circulations, local winds such as sea breeze, and orography. Highest annual average amount of lightning are evident in Kegalle and Gampaha districts. Seasonally, a bi-model pattern of lightning occurrence is visible with maxima during the first intermonsoon season (FIM, March to April) and the second highest in the second intermonsoon season (SIM, October to November); the lowest amount of lightning are observed in the northeast monsoon season. Monthly variability shows that the maximum number of lightning is observed in April during the FIM season. The analysis of this study provides useful information of spatial and temporal pattern of lightning activity during the four climatic seasons in Sri Lanka, and the results can be used especially in decision-making and disaster risk management to aid, for example, in the understanding of where to focus safety education to reduce lightning fatalities and injuries

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1 Introduction

Thunderstorms are one of the most common and most noticeable weather events containing multiple dangers that can threaten safety including heavy rain, lightning, strong winds and hail. As one of the most deadly weather related phenomena, lightning has a very wide spatial and temporal distribution. Observations of lightning can be traced back to 1746 and after more than 250 years, ground-based and satellite-based lightning locating technologies exist at present (Zeng et al., 2016).

Lightning causes a number of fatalities in Sri Lanka each year, as well as significant economic losses. At least 50 persons in Sri Lanka are been killed by lightning each year (Gomes & Ab Kadir, 2011).

The lightning density (LD hereafter) is defined as the number of lightning, including cloud-to-ground and intra-cloud lightning, over a unit area in unit time, to describe lightning activity (Kuleshov, 2012). LD of a given region has a strong correlation with the annual figure of lightning casualties (Gomes & Ab Kadir, 2011). Consequently, understanding the spatial and temporal variability of lightning activity provides important information for the general public, decision makers in disaster management, for improvement in nowcasting of lightning hazards, and for identifying and planning for lightning hazard mitigation (Dewan et al., 2018; Roeder et al., 2015; Wapler, 2013).

Early studies have examined the spatial and temporal variation of thunderstorms over Sri Lanka using thunder day data of 20 meteorological stations for 20 years (Sonnadara, 2016). Thunder day is defined as simply a calendar day in which thunder is heard at least once at a given location (WMO, 1956). With the topographical complexity of Sri Lanka, spatial variation of lightning activity based on number of thunderstorm days collected by 20 meteorological stations does not well represent the actual spatial variability of lightning activity. Furthermore, as lightning is generally associated with the mesoscale convective systems having very high temporal and spatial variability, data with higher spatial resolution is essential to study lightning activities (Ranalkar & Chaudhari, 2009).

Lightning location data by lightning detection networks allow the observation of continuous lightning data with high spatio-temporal accuracy (Bovalo et al., 2012; Enno, 2011), because it provides location specific information with time, latitude and longitude for each lightning stroke and an overview of the number and spatial distribution of lightning strokes.

The purpose of this study is to understand the spatio-temporal variability of LD over Sri Lanka using high spatial resolution lightning dataset. In Sect. 2 we present the dataset and methods, and in Sects. 3 and 4 the results and discussion. A summary and conclusions are presented in Sect. 5.

2 Data and Methodology

Vaisala GLD360 lightning location data (Demetriades et al., 2010) provided under the collaborative project "Severe Storm Warning Services for Sri Lanka (SSWSS)" is the primary data used in this study. Vaisala GLD360 global lightning dataset provides both arrival time and geo-location as well as other lightning parameters (e.g., peak current) of individual lightning strokes (Said & Murphy, 2016). GLD360 has a great potential to be used in monitoring thunderstorms in real-time with large coverage (Pohjola & Mäkelä, 2013) with cloud-to-ground flash detection efficiency of 86% to 92% (Demetriades et al., 2010). Hence GLD360 is suitable to analyze spatio-temporal variability in Sri Lanka as this dataset provides observation of continuous lightning data that includes high resolution of location specific information with time, latitude and longitude. Previously, the GLD360 data has been used for similar purposes in Nepal (Mäkelä et al., 2012). GLD360 provides the temporal and spatial information of individual lightning strokes, which in this study are not grouped to flashes nor to cloud-to-ground or intra-cloud lightning types. Note: since 2019, the GLD360 data is classified as cloud-to-ground or intracloud, but for the analysis of this study that categorization was not present.

Location specific GLD360 data for the period 2015–2018 were converted into point vector layer in GIS environment using ArcGIS software. A vector grid of 2 km × 2 km was created. The spatial joining of shape file with vector grids has been done to obtain the lightning counts in each respective grid cell. Consequently, the hourly, monthly, seasonal and annual LD were calculated to see the spatial and temporal variability. The climatic seasons of Sri Lanka are distinguished only by means of the timing of the two monsoons and the transitional periods separating them, called inter-monsoon seasons (Chandrapala, 1996). Seasons considered here are First Inter-Monsoon (FIM, March–April), Southwest Monsoon (SWM, May–September), and Second Inter-Monsoon (SIM, October–November) and Northeast Monsoon (NEM, December–February). During the Inter-monsoon seasons (*i.e.*, both FIM and SIM) most convective activity is associated with the formation of mesoscale circulations due to differential heating caused by horizontal variations in land surface characteristics (Jayawardena et al., 2020). As lightning strokes during January 2017 and February 2017 were missing in the data set, LD maps for only 2 NEM (2015 NEM season and 2017 NEM season) seasons were constructed and annual LD map for 2017 was created using 10 months of data. Seasonal LD presented in this study are divided by number of months in each season in order to see the seasonal changes of lightning activity more clearly. As districts in Sri Lanka are second level administrative divisions and play an essential component of disaster management, district mean LDs are computed for annual, monthly and seasonal time scales.

The digital elevation model (DEM) from the Shuttle, 'Radar Topography Mission' (SRTM) (USGS, 2005) was used to identify the influence of topography on spatial distribution of LD.

Ocean Nino Index (ONI; Kousky & Higgins, 2007) and Dipole Mode Index (DMI; Saji et al., 1999) are used to classify El Nino Southern Oscillation (ENSO) and Indian Ocean Dipole (IOD) events occurred during the study period respectively.

3 Results

3.1 Annual Lightning Activity

Annual average LD calculated from GLD360 data from 2015 to 2018 (Figs. 1 and 2) shows remarkable spatial variation, ranging from less than 20 strokes km^{-2} year^{-1} (st km^{-2} yr^{-1} hereafter) along the coastal areas except western and southwestern coastal areas, Jaffna Peninsular, and high elevation areas of central hills to more than 150 st km^{-2} yr^{-1} in the inland areas of western parts of the country.

The western part of the island shows higher annual LD than the eastern part. There are enhanced LDs along the western and southwestern foothills (Fig. 2), suggesting a link to the sea breeze and orographic lifting. The three hotspots of high LDs, indicated by rectangles in Fig. 1, are found in north-central province (A), along western foothills of central hills exceeding 100 st km^{-2} yr^{-1} (B), southeastern foothills (C). The highest LD of more than 200 st km^{-2} yr^{-1} was observed in a small area of the western part of the island, Ruwanwella divisional secretariat division in Kegalle districts. It is worthy to mention that higher lightning activity in the region depicted by A, is a major paddy cultivation region where people often work outside involved in agriculture activities during the day time and possibility of becoming victims of lightning fatality is high.

The LD maps and district mean annual LD for 2015 to 2018 are shown in Figs. 3 and 4 respectively. Least occurrence of lightning strokes is apparent in 2015 with disappearance of lightning maxima indicated in rectangle A in Fig. 1 over north-western and north central parts (Figs. 3 and 4).

Highest annual mean LD between 140 to 120 st km^{-2} yr^{-1} (Fig. 4) are reported from Kegalle and Gampaha districts while Colombo and Kalutara also reported more than 100 st km^{-2} yr^{-1} (Fig. 4). Significant lightning activity is also apparent in Kurunegala, Puttalam, Anuradhapura and Vavunia districts with around 70 to 80 fl km^{-2} yr^{-1} (Fig. 4). Above mentioned districts show higher values of LD in 2017 and 2018 (Figs. 3 and 4) while lesser values in 2016 and especially in 2015 (Figs. 3 and 4).

In order to investigate inter-annual variability, annual lightning counts for individual years and averaged from 2015 to 2018 is tabulated as presented in Table 1. On average, 3,064,647 lightning counts per year were reported by GLD360 (Table 1) over Sri Lanka. Occurrence of lightning is reduced by 20% both in the years 2015 and 2016 and it is being enhanced by 20% in 2017 and 2018, compared to 4 year average from 2015 to 2018. (Table 1).

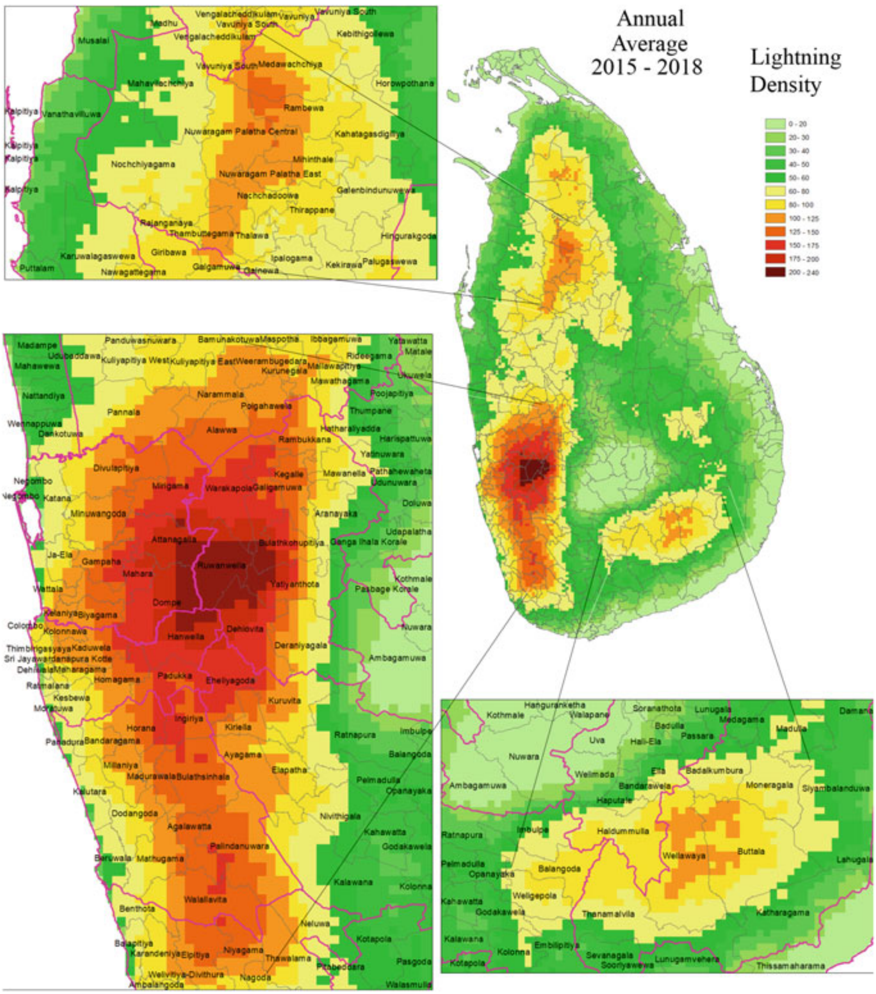


Fig. 1 Spatial distribution of annual average (2015–2018) LD (st km^{-2} yr^{-1})

3.2 Seasonal Lightning Activity

Highest seasonal LD is evident in the FIM followed by SIM, while it was least in NEM (Fig. 5). The western part of the island shows higher annual LD than the eastern part. Annual lightning activity is dominated by FIM lightning activity (Figs. 1, 3, 5, and 6). Lightning activity in the two monsoons is confined predominantly to leeward side but some lightning activity is detected in windward side during SWM (Fig. 5). Significant inter-annual variability in lightning occurrence is identified in SIM with a reduction in 2016 and an enhancement in 2015 and 2018 (Fig. 5). Least lightning

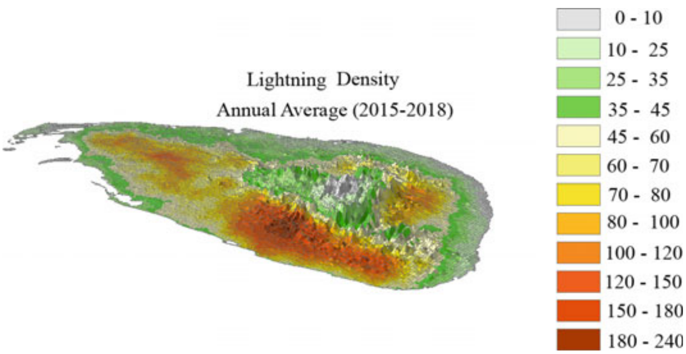


Fig. 2 Spatial distribution of annual average (2015–2018) LD (st km^{-2} yr^{-1}) overlay in SRTM DEM

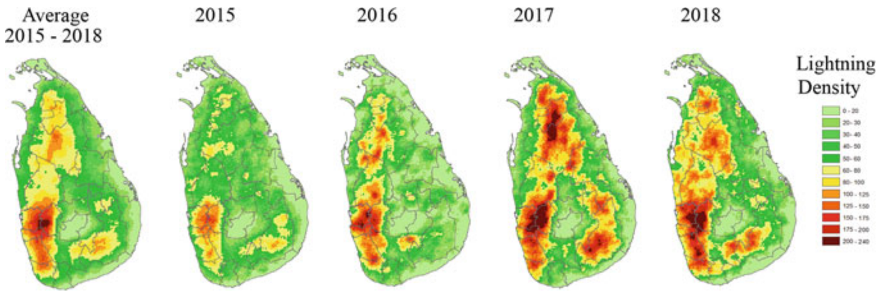
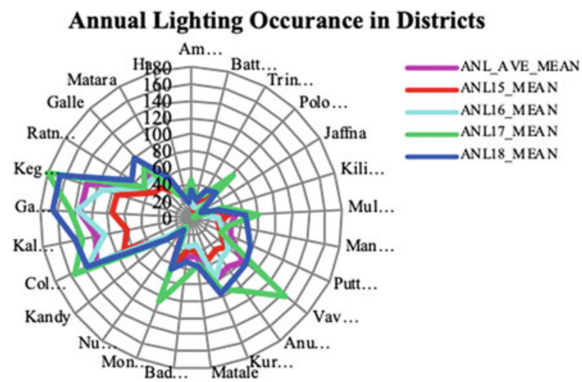


Fig. 3 Spatial distribution of annual LD (st km^{-2} yr^{-1}) from 2015 to 2018

Fig. 4 Distribution of district mean annual LD (st km^{-2} yr^{-1}) from 2015 to 2018



occurrence in FIM is apparent in 2015 while lighting activity is diminished during SWM in 2015 and 2016 (Fig. 5).

More than 50% of the annual lightning counts are reported during FIM season, except in FIM 2015 when lightning activity is diminished to 45% of annual lightning

Table 1 Annual total lightning counts reported by GLD360 over Sri Lanka

Year	Annual total lightning counts	Percentage from annual average (2015–2018) lightning counts (%)
2015 (Jan–Dec)	2,405,900	78.5
2016 (Jan–Dec)	2,539,900	82.9
2017 (Mar–Dec)	3,620,600	118.1
2018 (Jan–Dec)	3,692,200	120.5
Average (2015–2018)	3,064,647	

counts. SIM contributed 25% of annual lightning counts which enhanced up to 30 to 35% in 2015 and 2018 and then reduced to 20% in 2016 and 2017. The transition period of two monsoons, inter-monsoon period contributed ¾ of annual lightning activity in Sri Lanka.

Districts located in western and south western parts such as Kegalle, Gampaha, Colombo and Kalutara and Districts located in north-western and north central such as Kurunegala, Vavunia and Anuradhapura observed occurrence of more lightning in FIM, SWM and SIM seasons (Fig. 7). Trincomalee, Mullative, Polonnaruwa and Matale districts show lightning activity in the SWM season (Fig. 7).

3.3 Monthly Lightning Activity

Figure 8 shows the spatial variation of monthly LD for the period 2015–2018 over Sri Lanka. The mean monthly LD shows a peak in the month of April, followed by May, October, March and September. Lightning activity is more confined to western, southwestern and southern coastal region in November (Fig. 8). Least lightning activity is observed from December to February when lightning activity is limited to southwestern coastal areas and June to August when lightning activity is limited to eastern and northeastern coastal areas. It is noteworthy to mention that when monsoonal flow, either the SWM or the NEM is fully established over the country, lightning occurrence is low and narrowed to leeward side of the country (Figs. 5 and 8).

The mean monthly lightning counts show a peak in the month of April with on average 891,524 lightning counts. Highest lightning counts of 1,122,452 and lowest of 644,016 are observed in April 2016 and 2015 respectively (Fig. 9a). In general, lightning counts in April only contributed more than ¼ of the annual lightning counts. Moreover, nearly 50% of lightning counts recorded in 2016, occur from the month of April (Fig. 9b). Around 10–15% contribution is coming from May, October and March while 5–10% contribution comes from September and November. Rest of months plays a very small role in annual lighting counts (Fig. 9b). There is a significant year to year variation in lightning occurrence in September and October months with 90–40% reduction in the year 2016 and 20 to 30% reduction in the year 2017.

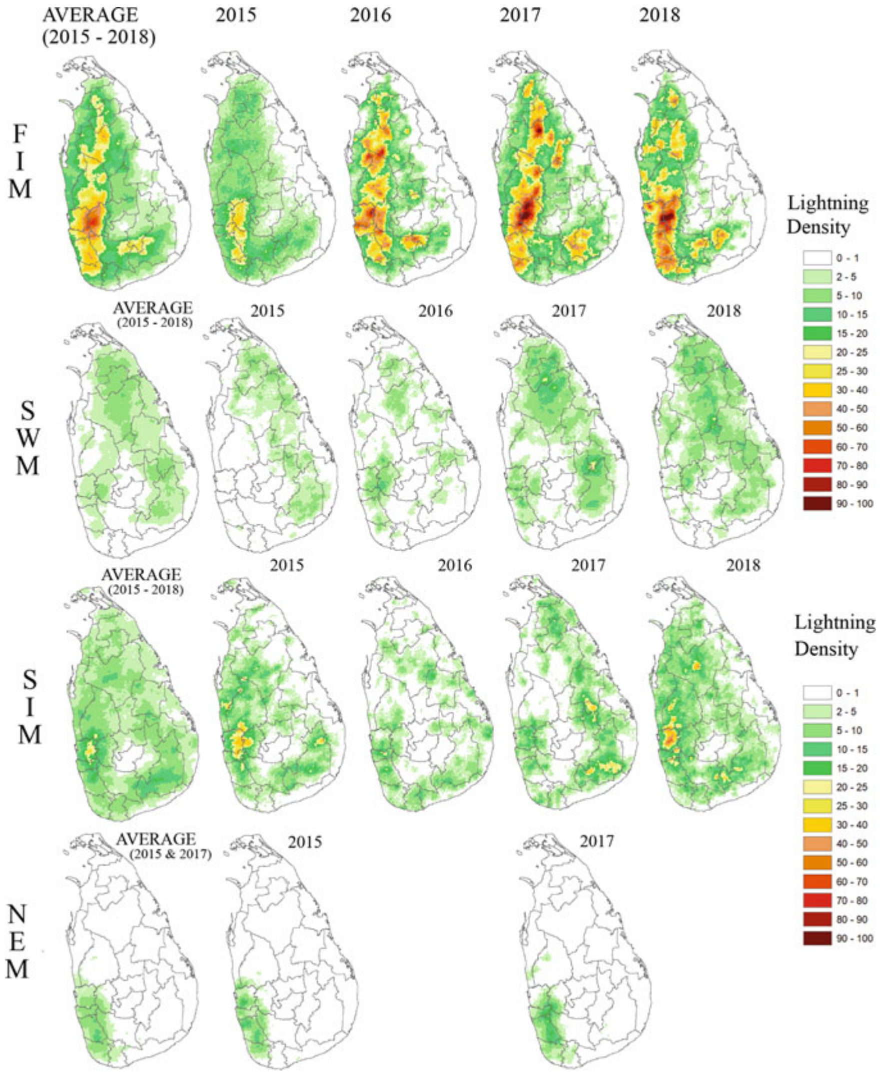


Fig. 5 Spatial distribution of seasonal LD (st km^{-2} month^{-1}) for 4 climatic seasons FIM, SWM, SIM and NEM from 2015 to2018

Furthermore, 90–40% and 20–30% enhancement of September and October lightning occurrence is observed in 2015 and 2018 respectively (Fig. 9b). Lightning activity in May is reduced by 40% in 2015 and is enhanced by 20% in 2016 and 2018. March lightning activity is reduced by 35% and 50% in 2015 and 2016 respectively and increased by 70% in 2017 (Fig. 9a).

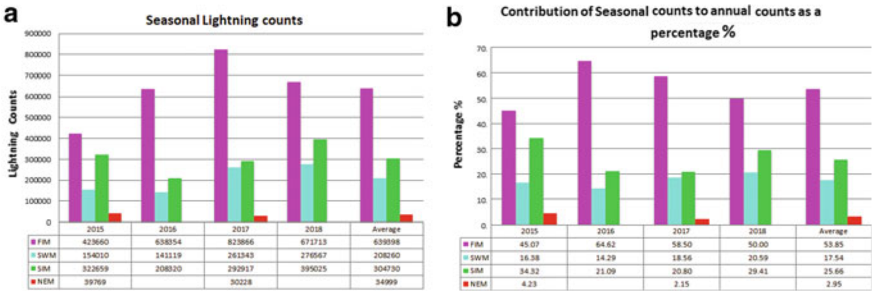


Fig. 6 Seasonal lightning counts (counts per month) (**a**) and contribution of seasonal lightning counts to annual total lightning count as a percentage (**b**) from 2015 to 2018

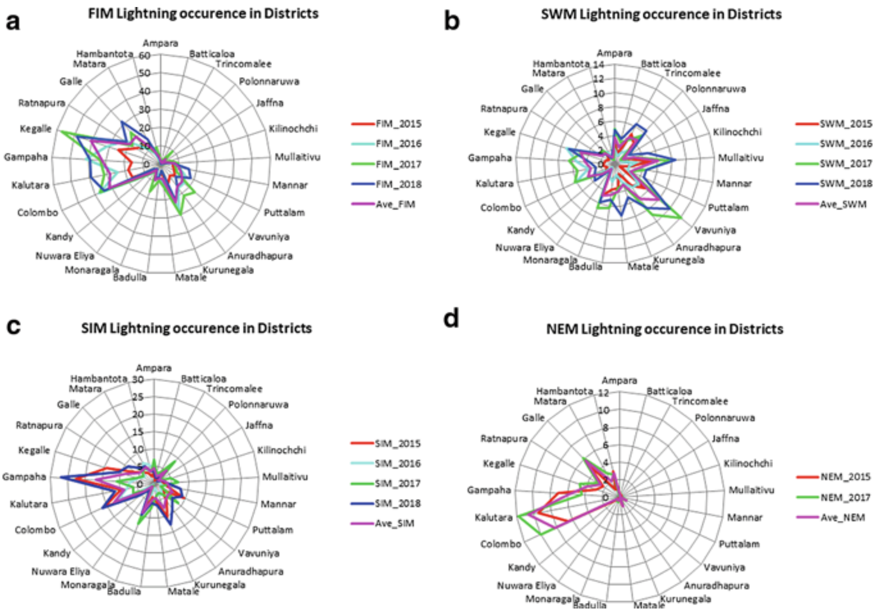


Fig. 7 Distribution of district mean of seasonal LD (st km^{-2} month^{-1}) for FIM (**a**), SIM (**b**), SWM (**c**), and NEM (**d**) from 2015 to 2018

A widespread lightning activity observed during May and October is in agreement with the propagation of the Inter Tropical Convergence Zone (ITCZ) twice a year around these two months over Sri Lanka.

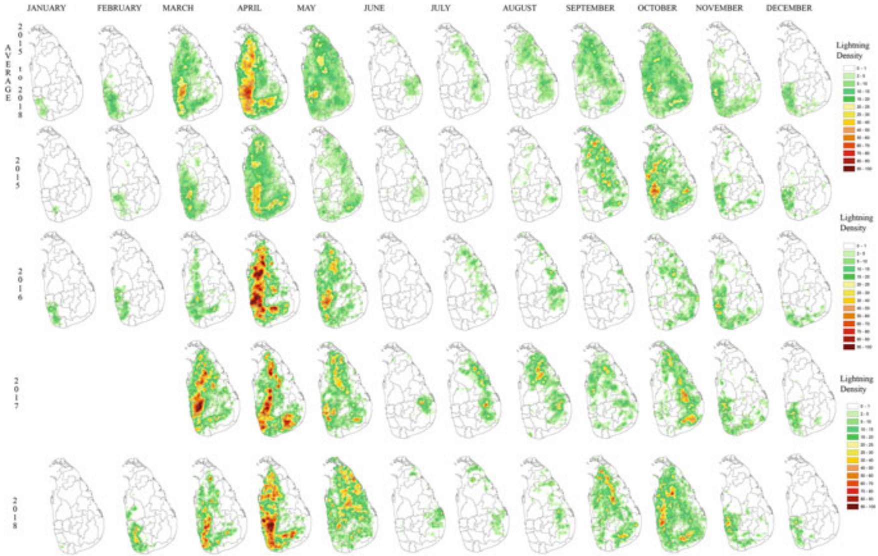


Fig. 8 Spatial distribution of monthly LD (st km^{-2} month^{-1}) from 2015 to 2018

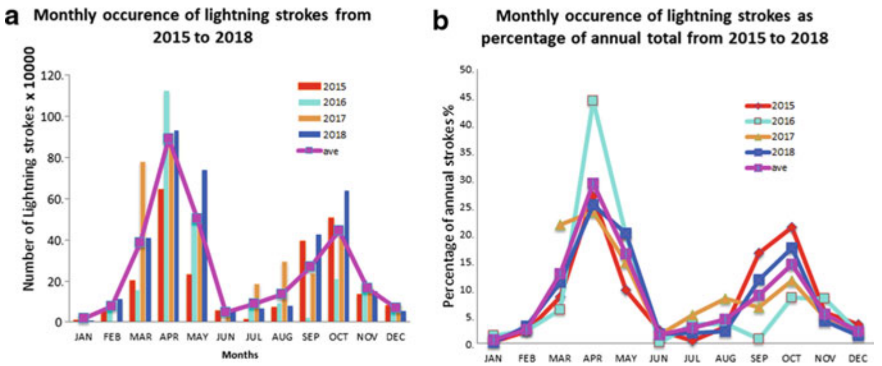


Fig. 9 Temporal distribution of monthly lightning counts (**a**) and contribution of monthly lightning counts to annual lightning count as a percentage (**b**) from 2015 to 2018

3.4 Diurnal Variation of Lightning

Diurnal variation of lightning counts during 2015 to 2018 shows a peak between 1530 to 1730 LST (Fig. 10) which is coherent with previous studies (Nag et al., 2017; Weerasekera et al., 2001). Lightning maxima around late afternoon is a common global feature. Lightning maxima in late afternoon indicates that most convective activity in Sri Lanka is associated with the land surface heating.

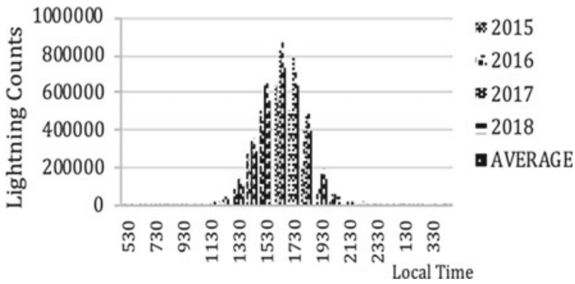


Fig. 10 Hourly lightning counts from 2015 to 2015 over Sri Lanka

4 Discussion

Temporal variations of diurnal, monthly and seasonal lightning occurrence found in this study are in agreement with the previous studies by Nag et al. (2017), Sonnadara (2016) and Weerasekera et al. (2001). Spatial variations of SWM and NEM are also consistent with previous studies (Nag et al., 2017; Sonnadara 2016; Weerasekera et al., 2001). However, spatial variations of annual LD identified in this study, such as highest LDs in Kegalle and Gampaha districts, are in contrast to the previously reported results (Sonnadara 2016) that used Mackerras and Eriksson's formulas to derive the LD from average annual thunder day data where maximum activity in lightning was found in Ratnapura district.

4.1 Influence of Climate Modes on Lightning Activity

ENSO and IOD are climate modes of inter-annual variation of the ocean–atmosphere system in tropical Pacific region and Indian Ocean. Previous studies identified that ENSO and IOD seems to play a major role in the inter-annual variability of the SIM rainfall over Sri Lanka. Rainfall enhancement is evident during EL Nino (Rasmussen & Carpenter, 1983; Suppiah, 1997; Zubair & Repelewski, 2006) and Positive IOD (Chandimala & Zubair, 2007) while rainfall reduction appeared during La Nina and negative IOD in SIM. However, there are only a few studies addressing the impact of ENSO and IOD on lightning activity in Sri Lanka region. According to a study conducted by Bovalo et al. (2012) on lightning activity in the South West Indian Ocean including Sri Lanka, ENSO and IOD play an important role in the modulation of lightning activity in the region. Investigating the spatial temporal variability of the convective parameters and associated lightning lightning rates during the period 1997–2013 including the El Niño and La Niña episodes, Saha et al. (2017) revealed that enhanced lightning activity over South/South-East Asia region during El Niño, compared to La Niña.

A marginal El Nino condition appeared from the beginning of 2015, intensified into strong El Nino by May 2015 which persisted till March 2016 (Fig. 11a). A borderline La Nina has developed in the latter parts of 2016 and 2017. Marginal El

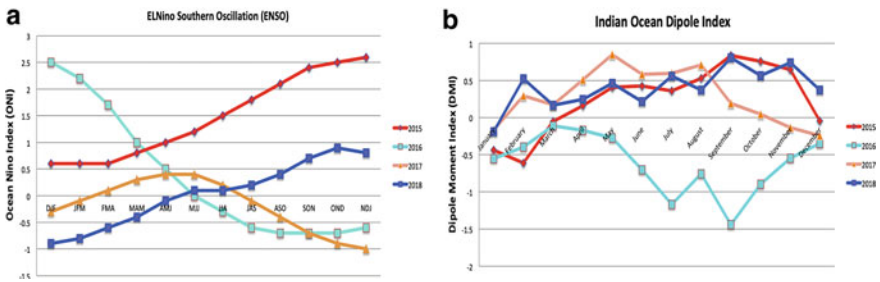


Fig. 11 3 monthly Ocean Nino Index (**a**) and monthly IOD index (**b**) from 2015 to 2018

Nino was developed in the latter part of 2018. Positive IOD has developed in the latter parts of 2015 and 2018 (Fig. 11b). Negative IOD appeared in the latter part of 2016. As SIM is dominated by convective activity, enhancement of convective activity with higher lighting occurrence in SIM 2015 and 2018 may be linked to the El Nino and positive IOD (Figs. 5, 6 and 11). Weak La Nina with negative IOD in latter part of 2016 may have reduced the convective activity with lesser lightning counts in SIM 2016. Even though a borderline La Nina conditions developed in the latter part of 2017, a significant reduction of lightning counts is not evident in SIM 2017 compared to SIM 2016. Neutral IOD present in the latter part of 2017 may be a possible reason for this discrepancy of lightning occurrence (Figs. 5, 6 and 11). El Nino and positive IOD present in 2015 and 2018 (Fig. 11) enhance while La Nina and negative IOD in 2016 (Fig. 11) tend to reduce the occurrence of lightning in the months of September and October (Figs. 8 and 9). However lightning occurrence in November may not be significantly impacted by ENSO and IOD modes of variability (Figs. 8 and 9).

As the dataset used in this study is limited to 4 years from 2015 to 2018, the length of the dataset is still too short to identify the relationship between lightning activity and modes of variability.

5 Conclusion

Spatial and temporal variations of lightning activity in Sri Lanka were studied using Vaisala GLD360 data from 2015 to 2018. Three hotpots of annual lightning activity along the western foothills of the central hills, over north-central province, and in along the south-eastern foothills were identified. Least LD were found along the coastal areas except western and southwestern coastal areas, Jaffna Peninsula, and high elevation areas of central hills. Highest district mean lightning densities of about 130 fl km^{-2} yr^{-1} were reported from Kegalle and Gampaha districts followed by 125 fl km^{-2} yr^{-1} in Colombo district.

On average, 3,064,647 lightning counts per year were reported from 2015 to 2018 over Sri Lanka. Annual lighting occurrence is dominated by FIM season contributing

50%, and then followed by 25% from SIM to annual lightning occurrence. Least lightning activity is found in NEM. During the inter-monsoon period, as there is no predominant wind flow over Sri Lanka, prevailing variable light winds and convective activity associated with the formation of mesoscale circulations due to differential heating caused by horizontal variations in land surface characteristics, together with orographic lifting, contributed to account for ¾ of annual lightning activity in Sri Lanka. ENSO and IOD may have modulated the lightning occurrence in the months of September and October.

The analysis of this study provides a useful reference of when and where the high lightning activity occurs in Sri Lanka. Through raising community awareness for people living in high lightning activity areas and taking proper measures, Sri Lanka will be able to mitigate the adverse effect of lightning hazards in the near future. Communities themselves must take some initiatives for reducing the damage done by lightning. Further establishment of lightning detection system for monitoring and early warning are essential to enhance disaster risk reduction in Sri Lanka.

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Analysis and Comparison of the Earthquakes Over the Indonesian and Makran Zones: Towards Possible Tsunami Generation in Future

Sarath Premalal, Sunil Jayaweera, and Asitha de Silva

Abstract Sri Lanka is in the south eastern part of Indian plate closer to Australian plate and surrounded by Eurasian plate, Australian plate, African plate and Arabian plate. Except, plate boundaries between Indian plate and Eurasian plate, all the other three plate boundaries around Sri Lanka are divergent. However, plate boundaries between Eurasian Plate and Arabian Plate, and Eurasian plate and Australian Plate are convergent and also subduction zones. Therefore, there is a chance of generating tsunamis from earthquakes having higher magnitude in these two plate boundaries which known as Indonesian subduction Zone and Makran subduction Zone respectively. Sri Lanka was hit by a major tsunami in 2004 due to the massive earthquake occurred in Indonesian subduction zone. Many changes have been occurred after the tsunami like establishment of present warning system, communication system and development of criteria for tsunami generation. According to the present tsunami generation criteria, the magnitude of the earthquake should be greater than 6.5 and the epicenter should be less than 100 km depth in the ocean to generate a tsunami. But most of the ocean wide tsunamis were generated from the earthquakes greater than 7.9 and in the depths less than 100 km. Purpose of this study is to understand the spatio-temporal distribution of earthquakes and the preparedness of the Indonesian and Marakkan zones. The study is based on secondary earthquake data with having the magnitude greater than 6.5. Seventy (70) years USGS data were used for the period 1950 to 2020. Analysis further extended to categorize the data according to the present criteria. Moreover, a comparison of earthquake events between Indonesian region and Makran zone also identified. The study also focused on policies and institutional capacities within the region and how they have improved from 2004 tsunami. Analysis clearly showed that, the number of earthquakes is much higher

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during the last 3 decades compared to the previous three decades. In addition, earthquakes which having possible tsunami generation is also higher during the last three decades.

Keywords Plate boundaries · Earthquake · Tsunamis

1 Introduction

A tsunami is a series of waves or surges most commonly caused by an earthquake beneath the seafloor. "Tsunami" is a system of ocean gravity waves formed as a result of large scale disturbance of the sea bed in a short duration of time, mostly due to an earthquake or volcanic eruption or submarine landslide (Nayak & Kumar, 2008). Tsunamis can cause great loss of life and property damage in coastal areas. Very large tsunamis can cause damage to coastal regions thousands of miles away from the earthquake that caused them.

The word "tsunami" is new for people in Sri Lanka until 2004. The Indian Ocean Tsunami with a magnitude of 9.2 in Richter scale, on 26th December 2004 resulted in the loss of over 230,000 lives (Anputhas et al., 2005), over the Indian ocean locally and as far away as Africa, including over 2,500 foreign tourists, and the displacement of over 1.6 million people around the Indian Ocean, with economic losses of about $14 billion in Sri Lanka. Tide gauge at Colombo fisheries harbour recorded 2.6 m height tide at about 1000 SLST. 2004 Tsunami was one of the world's largest since 1900. The devastating tsunami resulting from it caused more casualties than any previously reported tsunami (Wijeyewickrema et al., 2006). The earthquake ruptured the seafloor surface and displaced the water column above it by several meters where the resulting wave heights near the epicentre were determined to be 32 m high (Jordan, 2008).

In total, 16 major tsunamis killed 250,900 people in 21 countries between 1996 and 2015. More than 3000 people were killed in the town of Hambantota located in south eastern Sri Lanka (6.2500°N, 81.1667°E) (Anputhas et al., 2005). 2015 United Nations (UN) report estimated that each year, about 60,000 people and $4 billion (US$) in assets are exposed to the threat of tsunami hazards. Impacts from the tsunamis are very high compared to the other hydro-meteorological disasters. Most of the Indian Ocean counties did not have the experience to face such a disaster (UNISDR, 2015).

As Benjamin, 2008 mentioned, the very large size tsunamis like the Indonesian tsunami, 2004 occurs not only because of the magnitude of the earthquake and seafloor rupture. There can be seafloor displacements taking place near a deep-sea trench, in very deep water (Geist et al., 2006). The depth of the Indian Ocean then supports the wave to travel great distances without losing much energy.

Tsunami waves can be reached from minutes to an hour and even within a day for the coastal areas after an earthquake. 2004 Indian Ocean tsunami was taken nearly one hour and twenty-five minutes to reach the Sri Lankan coast (Wijeyewickrema et al., 2006). On September 29, 2009, South Pacific Tsunami in the Tonga Trench arrived in Tonga, Samoa, and American Samoa within 5–15 min after they felt the earthquake and after the shaking has stopped. The 1960 Chilean tsunami propagated more than 17,000 km across the Pacific Ocean, causing casualties in Hawaii and Japan, and the Philippines. Therefore, estimating the probability of tsunami generation after an earthquake is an important part of disseminating a warning to the last mile.

There was no Tsunami warning system and no criteria to issue warning to the Indian Ocean countries, before 2004. In the present scenario, the Department of Meteorology (DoM), Sri Lanka is mandated to issue alerts for possible tsunami generation if an earthquake occurs in the Indonesian region or Makran zone (near shore or offshore) with a magnitude greater than 6.5 and the depth from epicentre less than 100 km with the information disseminated by Tsunami Service Providers (TSP) to the Indian Ocean. Disaster Management Centre in Sri Lanka estimates the threat and disseminate it to the vulnerable communities via many stakeholders and using several modes of communication. The present criteria of issuing tsunami warnings are based on the information from the Pacific Ocean (IOC, 2011) and the information given by "Indian Tsunami Early Warning Centre User Guide, Version-2", for the Indian Ocean.

IOC, 2009, mentioned descriptive criteria based on the depth and the magnitude. According to the report, the depth of an earthquake from the epicentre should be less than 100 km in the sea. Very small potential for a destructive tsunami, for the magnitude 6.5 and 7.0. However, there is a potential for a destructive local tsunami if the magnitude between 7.0 and 7.5. It is possible to generate a destructive regional tsunami for a magnitude between 7.6 and 7.8. An ocean wide destructive tsunami can be expected for a magnitude greater than or equal to 7.9.

Based on several tsunami case studies in the Pacific Ocean, Paul Whitmore et al. (2008) concluded that there is less than 1% chance to generate tsunamis with an earthquake having a depth greater than 100 km from the epicentre in the Pacific Ocean. According to Paul Whitmore, there is a 90% chance to generate tsunamis with an earthquake having a depth of less than 50 km from the epicentre. More-over, there is a 59% chance to generate tsunamis with an earthquake of magnitude greater than 7.9. The chances of generating tsunamis for the magnitude between 6.5 and 7.0 M is 0.75%. There are some pitfalls in using modelling to base criteria for the local events. Most sub-sea earthquakes less than or near a magnitude of 7.5 do not trigger significant tsunamis.

According to historical tsunami events, Sri Lanka is not much vulnerable since Sri Lanka is located far from both the Indonesian subduction zone and the Makran subduction zone. Moreover, there may not be a threat from local or regional tsunamis. However, it is necessary to pay more attention to the earthquakes over the Andaman Sea even if the magnitude fit for the destructive regional tsunami as the distance to Sri Lanka is not much. Analysis of historical tsunamis in the Indian Ocean and impacted areas may provide information for the possible tsunami threat to Sri Lanka.

Therefore, this study is focused on analysing the historical earthquakes since 1900 in the sea area over the Indian Ocean, Indonesian region, and Makran Zone which magnitudes are greater than 6.5 and depth is less than 100 km. The number of decadal events also calculated and fitted into a trend line. Finally, historical tsunami events were analysed and categorized to check whether the criteria provided by UNECSCO, 2009 is valid in the Indian Ocean.

As another aspect this study tends to understand the preparation of Sri Lanka as a country for a future tsunami event. Therefore, another objective will be understanding the institutional and stakeholder preparedness based on the existing policies and implemented bylaws in the country related to DRR and resilience.

2 Methodology

The study was based on secondary data obtained from several sources and primary it can be divided as earthquake data and literature from academic and institutional sources. Earthquake information for the period 1900–2019 was downloaded from United State Geological Survey (USGS) website for the Indonesian subduction zone and the Makran subduction zone. Figure 1 shows the two areas of study and the two domains where the data were downloaded. Indonesian subduction zone locates between South Latitude 14.881 to 17.476 North Latitude and East Longitude 77.520

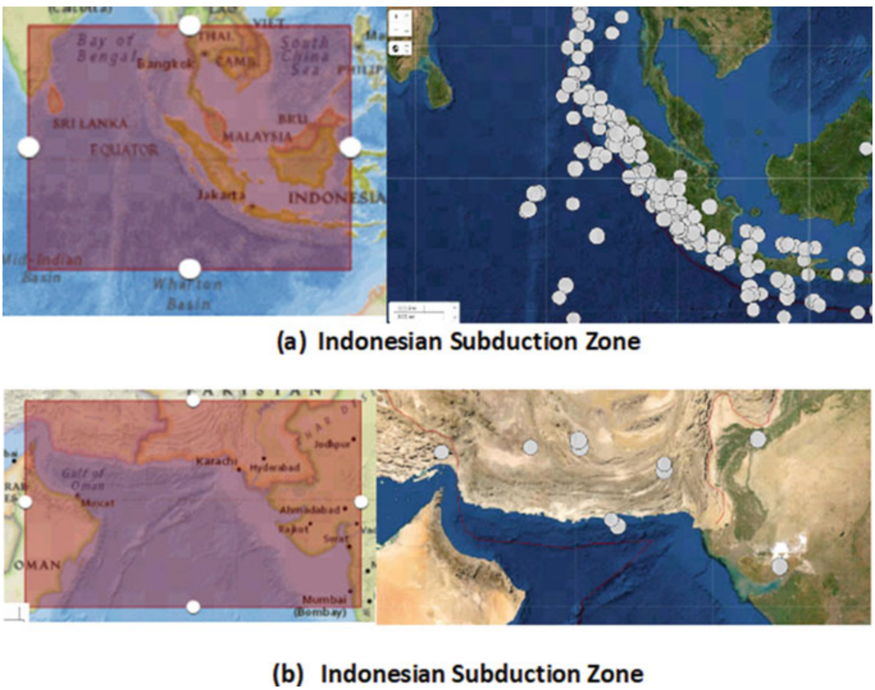


Fig. 1 Selected areas of study

to 119.004. The Makran subduction zone is located between North Latitude 18.062 to 28.227 and East Longitude 55.547 to 74.53.

Earthquake data were selected based on two physical parameters. Recorded cases with a magnitude greater than 6.5 in the Richter scale and the depth of occurrence is less than100 km, which are the basic criteria for tsunami generation (IOC, 2011). However, no tsunamis are generated from the earthquakes that occur on land, even the physical parameters are the same as above. Therefore, earthquake data that occurred on the land has been excluded from the analysis.

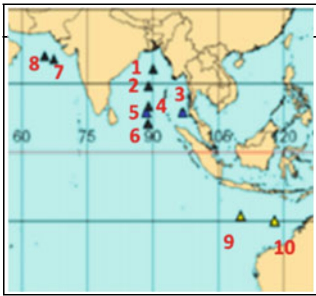
A decadal analysis has been conducted to identify the long-term trends of earthquakes. In addition, data were classified into different magnitude ranges as in 6.5–7.0, 7.1–7.5, 7.6–8.0, 8.1–8.5, 8.6–9.0, and above 9.1. From the decadal analysis percentage of occurrence has been calculated for the major earthquakes.

One of the objectives of this study is to identify the possibility of tsunami generation in the Indian Ocean from different magnitudes of earthquakes. It is important because to identify the clear criteria of tsunami generation as mentioned in the IOC, 2009 for Sri Lanka for preparedness, planning, and especially for early warning. Historical cases of tsunami generation since 1900 in the Indonesian subduction zone and Makran subduction Zone were obtained based on previous research articles from "NOAA Centre for Tsunami Research", and Wikipedia. Historical Tsunamis, their location, magnitude, and date are shown in Table 1 along with their source of reference.

There was no system to monitor, tsunami waves travel in the deep ocean before reaching the coast. DART BUOY is the main solution to monitor tsunami waves as it measures bottom pressure (converted to equivalent water depth) time series because

Table 1 Information of historical tsunamis in the MSZ and ISZ since 1900

Date	Mag	Name of the Location	References
28.09.2018	7.5	Sulawesi	Wahyu et.al. (2019)
02.03.2016	7.8	Southwest of Sumatra	Mohammad Heidarzadeh (2017)
11.04.2012	8.6	Sumatra	Dailin Wang et al.
25.10.2010	7.7	Mentawai, Indonesia	Alexandre Sahal and Julie Morin (2012)
06.04.2010	7.8	Sumatra	Wikipedia
10.08.2009	7.5	Andaman Islands	Mahesh et al. (2011)
12.09.2007	8.5	Sumatra	Jose C. Borrero (2011)
17.07.2006	7.7	South Java	Jim Mori et.al. (2007)
28.03.2005	8.6	Indonesia	Jose C. Borrero (2011)
26.12.2004	9.1	Indian Ocean	Anputhas et al. (2005)
03.06.1994	7.8	Java earthquake	(Wiki) Jim Mori (2007)
28.11.1945	8.1	Eastern Makran near Pasni	Rajendran et al.
04.01.1907	7.5–8.0	Simeulue, Nias off Sumatra	Stacey et al. (2019)



ID	ESTD	ID	ESTD
(1) 23223	14.11.2014	(6) 23227	25.10.2011
(2) 23219	07.03.2014	(7) 56001	17.10.2008
(3 23218	23.06.2016	(8) 56003	21.10.2008
(4) 23461	28.01.2017	(9) 23228	27.10.2011
(5) 23401	18.12.2006	(10) 23226	07.03.2014
DART BUOY in the Indian Ocean, Arabian Ocean, ID Numbers, and period of availability of data			

Fig. 2 DART BUOY and there locations

the wavelength of tsunami waves in the deep ocean is very long and it cannot be detected by any other instruments like Tide Gauges.

First DART BUOY has been installed in 2006 and the data availability of the DART BUOY system in the Indian Ocean is shown in Fig. 2. Along with the relevant periods of establishment and the locations. Analysis of the DART BUOY records have helped in identifying the recent tsunami generation activities in Indonesian and Makran subduction zones.

Along with secondary earthquake data and the archival records, a literature survey was conducted to investigate on the preparedness and early warning dissemination capacities of south Asian region with especial reference to Sri Lanka.

Under the literature survey an emphasis was given to Sri Lankan Government enacted “Disaster Management Act” in 2005, National Emergency Operation Plan (NEOP), and National Disaster Management Plan (NDMP) which have implemented in Sri Lanka with regards to disaster risk reduction. These policies are focusing on preparedness, mitigation, awareness, and early warning which are the main activities related to DRR. A review of these sources has conducted to understand the preparedness level of the country in case of an earthquake.

3 Results and Discussion

3.1 Evidence from the DART BUOY Records

There are several previous tsunamis recorded in DART BUOY laid over the Indonesian and Makran subduction zones. These DART BUOY are continuously monitoring the bottom pressure of the oceanic beds and several incidents were reported and recorded as tsunami events. Details of the tsunami generation and recorded waves on DART BUOYs are discussed below.

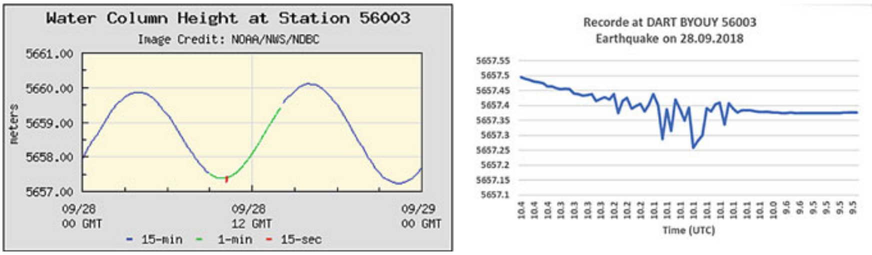


Fig. 3 Recorded wave at DART BUOY 56,003

Tsunami on Sep 28, 2018 (0.18 N, 119.85 E)

On September 28, 2018, at 18:02:44 Central Indonesia Time (UTC + 8), Palu Bay was hit by a strong earthquake with a magnitude of 7.5. The epicentre was located at 0.18° North latitude and 119.85° East longitude at a depth of 11 km, and 27 km northeast of Donggala City. As of October 21, 2018, official records confirmed that 2,113 people were killed, 1,309 missing, and 4,612 injured. In addition, 66,238 houses were damaged (Widiyanto et al., 2019). Propagation of tsunami waves was recorded at the DART BUOY 56,003 (Fig. 3). Recorded amplitude was up to 1.5 cm and the origin time was 12:49:48UTC.

Tsunami on Mar 2, 2016 (4.908 S, 94.275 E)

March 02nd, 2016 at the location of 4.908° South latitude and 94.275° East longitude, there was an earthquake at 12:49:48 UTC. It was originated from 659 km (409mi) southwest of Muara Siberut, Indonesia. There was a small tsunami, generated due to a large strike-slip earthquake occurred within the Wharton Basin, offshore from southwest of Sumatra, Indonesia. The magnitude of the earthquake was 7.8 and the depth from the epicentre was 24 km (Heidarzadeh et al., 2017). Propagation of tsunami wave has been recorded at the DART BUOY 23,227 (Fig. 4).

Tsunami on Apr. 11, 2012 (2.3 N, 93.1 E)

At 08:39 UTC, April 11, 2012, an earthquake of a magnitude of 8.6 has occurred, off the northern coast of Sumatra at the location of 2.3 North latitude and 93.1 East

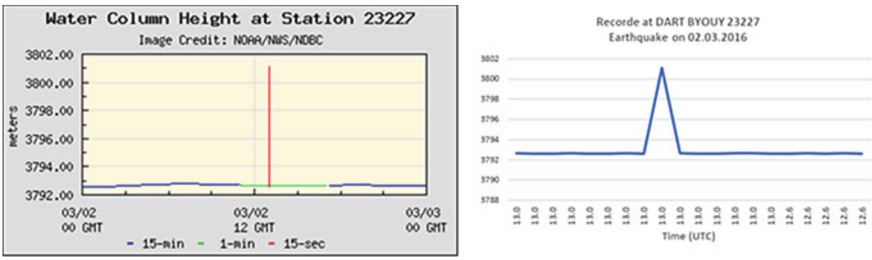


Fig. 4 Recorded wave at DART BUOY 23,227

longitude. There was another earthquake with a magnitude of 8.2, which originated approximately 180 km to the south after two hours from the first one. Tsunami warnings were issued by the governments of India, Indonesia, Sri Lanka, Thailand, and the Maldives (Wang et al., 2012). Propagation of tsunami waves was recorded at the DART BUOY 23,401 and 23,227 (Fig. 5).

Tsunami on October 25, 2010 (3.484 S, 100.114 E)

On October 25, 2010, at 14:42:22 UTC (18:42 local time in La Re´union), an earthquake occurred in the Kepulauan Mentawai archipelago located at 3.484 South latitude and 100.114 East longitude, near Indonesia with a magnitude of 7.7. The Pacific Tsunami Warning Centre (PTWC) issued a tsunami bulletin, seven minutes later, informing the Indian Ocean countries that an earthquake with the magnitude 7.5 had occurred and posed a local tsunami risk to Indonesian coastal areas. The tsunami reached run-ups of 7.3 m a few minutes later on the Pagai Islands, Indonesia, with waves of more than 9 m high (Martin et al., 2019). Propagation of tsunami waves was recorded at DART BUOY 56,001 (Fig. 6).

Tsunami on April 06, 2010 (2.383 N, 97.048 E)

On April 07, 2010, the Sumatra earthquake occurred at 5:15 AM local time with a magnitude of 7.8 and a depth from the epicentre of 31 km. The location of the earthquake was recorded as 2.383 North latitude and 97.048 East longitude. The shock occurred near Banyak Islands, off the island of Sumatra in Indonesia. A tsunami warning watch has been issued according to the Pacific Tsunami Warning Centre in Honolulu, which was later cancelled. A 40 cm surge was reported in the Banyak Islands an hour after the quake, along with 62 injuries. Power outages were reported

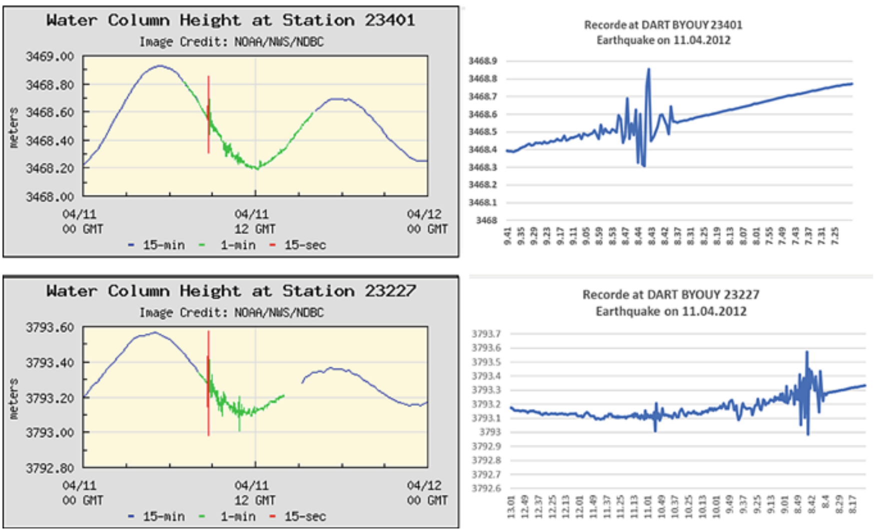


Fig. 5 Recorded wave at DART BUOYs 23,401 and 23,227

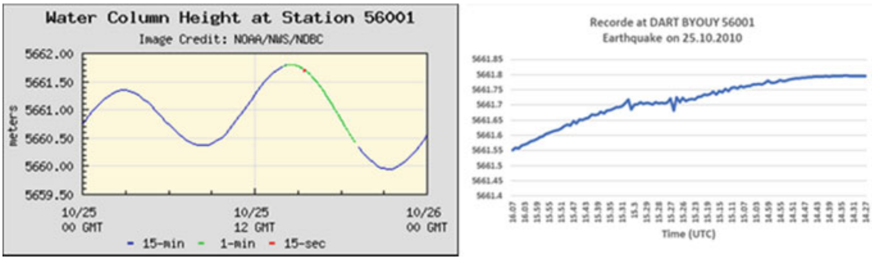


Fig. 6 Recorded wave at DART BUOY 56,001

throughout the province of North Sumatra as well as in Aceh. Propagation of tsunami wave was recorded at DART BYOUY 23,401(Fig. 7).

Tsunami, 10 Aug 2009 (14.099 N, 92.902 E)

On the 10th of August 2009, an earthquake has occurred about 50 km north of North Andaman Island, about 40–50 km west of the Great Coco Island, and about 60 km east of the Andaman trench (Mahesh et al., 2011). The location and the depth from the epicentre were 24 km from the surface at 14.099 North latitude and 92.902 East longitude. Propagation of tsunami wave was recorded at DART BUOY 23,401 (Fig. 8).

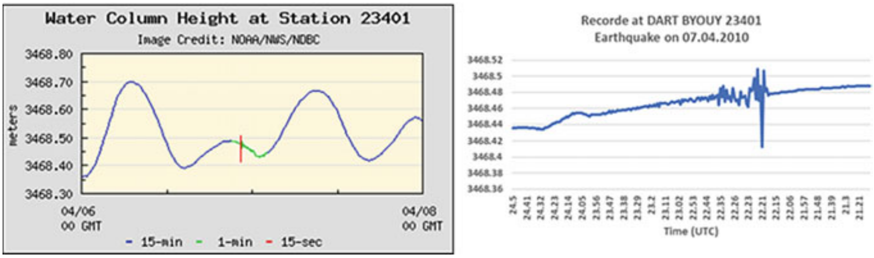


Fig. 7 Recorded wave at DART BUOY 23,401

Fig. 8 Recorded wave at DART BUOY 23,401

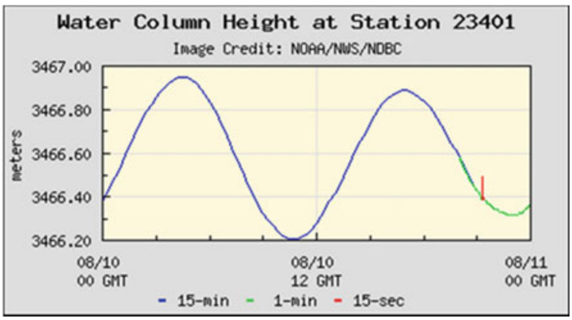
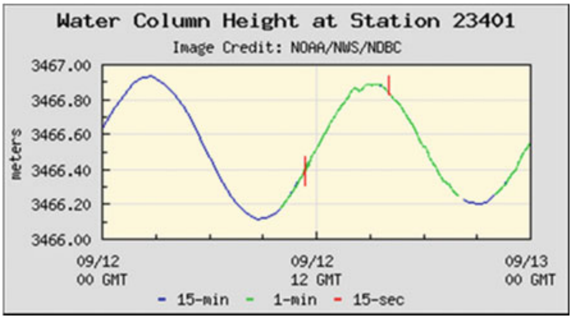


Fig. 9 Recorded wave at DART BUOY 23,401



Tsunami, September 12, 2007 (4.438 S, 101.367 N)

An earthquake of 8.4 magnitudes has occurred on 2007 September 12, offshore of the Bengkulu province of Sumatra, Indonesia, which generated a moderate tsunami with run-up heights of 4 m. The tsunami was observed along 250 km of coastline and caused damage at several locations. The largest wave heights and most severe inundation were observed in about 50 km to the northwest of Bengkulu; elsewhere the effects were less severe-with the exception of substantial inundation at a site of 150 km to the south (Borrero et al., 2009). The location of the earthquake is 4.438 South latitude and 101.367 North longitudes and the depth from the epicentre was 34 km. It was recorded at DART BYOUY 23,401 (Fig. 9).

Tsunami, July 17, 2006 (9.284 S, 107.419 E)

An earthquake of 7.7 magnitudes has occurred in the south of Java on July 17, 2006 (Mori et al., 2007). The location of the earthquake was 9.284 South latitude and 107.419 East longitude at a depth of 20 km from the epicentre. The thrust earthquake produced a large tsunami along the southern coast of Java with over 600 deaths and displacing over 75,000 people. During this event, only one DART BUOY was installed and there were no records.

Tsunami 2005, March 28 (2.07 N, 97.01 E)

A large earthquake with a magnitude of 8.6, occurred on March 28, 2005, at 11:09 p.m. local time (16:09 UTC), just a few hundred kilometres south of the most tsunami-devastated regions of Sumatra at the Sumatra Subduction Zone. The earthquake epicentre was located approximately at 2.07 North latitude and 97.01 East longitudes (USGS). The event caused substantial shaking damage and land level changes between Simeulue Island in the north and the Batu Islands in the south (Borrero Jose, 2011). It caused 340–1146 injuries, and 915–1314 deaths (Wikipedia).

Tsunami, December 26 2004 (3.295 N, 95.982 E)

The Indian Ocean Tsunami with a magnitude of 9.2 on 26th December 2004 resulted in the loss of over 230,000 lives (Anputhas et al., 2005). The location of the earthquake was 3.295 North latitude and 95.982 East longitude and the depth from the epicentre was 30 km.

Tsunami June 03, 1994 (10.477 S, 112.835 E)

On June 2, 1994, a large subduction thrust earthquake with a magnitude of 7.2 has produced a devastating tsunami on the island of Java (Abercrombie et al., 2001). The location of the earthquake was 10.477 South latitude and 112.835 East longitude and the depth from the epicentre was 18.4 km.

Tsunami, November 28, 1945 (24.927 N, 63.601 E)

Earthquake of Magnitude 8.1 occurred in 1945 and the consequent tsunami that originated on the eastern part of the Makran are the only historically known hazardous events in this region (Rajendran et al., 2013). The location of the earthquake was 24.927 North latitude and 63.601 East longitude and the depth from the epicentre was 15 km.

Tsunami January 04, 1907 (1.873 N, 94.209 E)

On 4 January 1907, an earthquake occurred off the west coast of Sumatra, Indonesia, with an instrumental surface wave with a magnitude ranging from 7.5 to 8.0. The tsunami it generated was destructive on the islands of Nias and Simeulue, where it killed hundreds of people. This tsunami was also observed in other parts of the Indian Ocean basin (Martin et al., 2019). The location of the earthquake was 1.873 North latitude and 94.209 East longitude at depth of 15 km from the epicentre.

As the data highlights the DART BUOY records for the Indonesian and Makran subduction zones are available after the Indian Ocean tsunami and there are no records prior to that. The records clearly highlighted that there is a high risk in Indonesian subduction zone compared to the Makran subduction zone regarding the possibilities of tsunami genic earthquakes. After installation of the DART BUOY in the area, the records are clearer, and it shows continuous occurrence of tsunami generic earthquakes with frequent intervals (Fig. 10). It is also clear that these tsunami genic earthquakes are well correlates with the UNESCO tsunami generation criteria.

Another point which highlighted by the records is that there is only one recorded tsunami genic earthquake in the Makran subduction zone. However, scientists have not undermining the risk and there are many studies have been ongoing to investigating the possible tsunami generation.

3.2 Earthquake Patterns and Its Characteristics

The decadal number of earthquakes in both land and the sea is shown in Fig. 11. According to the analysis, the 2001–2010 decade is the most active period for earthquakes. Nearly 27% of the earthquakes which have occurred starting from the decade of 1901–1910 fall into this decade. The second-largest earthquake also occurred in the same decade and it was in the year 2004. The analysis does not show a linear

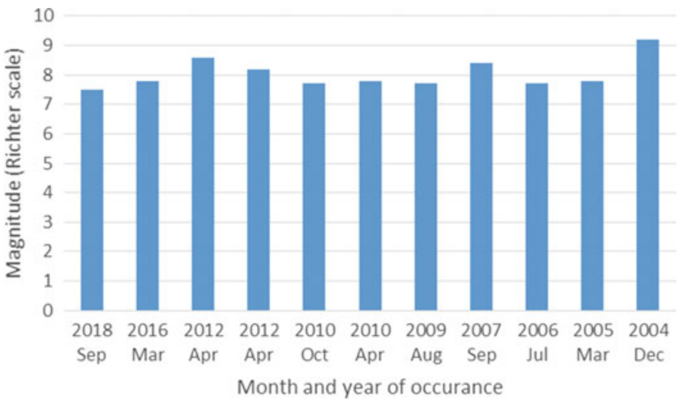


Fig. 10 Tsunami records after 2004 Indian ocean tsunami

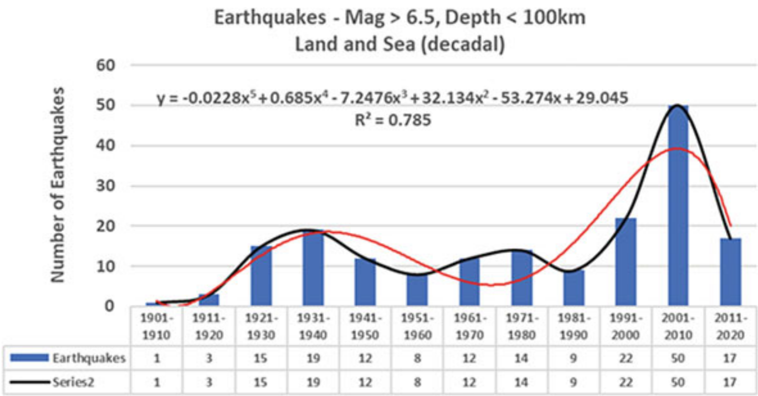


Fig. 11 Earthquakes by decades

trend, but it shows a higher number of earthquakes after 1990. The numbers are very less before 1920, and after that, the number of recorded earthquakes have increased. However, the pattern shows some sinusoidal behaviour with the increasing amplitude.

Data were fit into a fifth order polynomial equation (Red colour) and it shows statistical significant trend and the regression coefficient is 0.785

$$
\begin{aligned}
y &= -0.0228 \times 5 + 0.685 \times 4 - 7.2476 \times 3 \\
&\quad + 32.134 \times 2 - 53.274 \times + 29.045, \\
R^2 &= 0.785
\end{aligned}
$$

There were only 11 earthquakes that occurred in the Makran Zone since 1990. Out of 11, only two have occurred in the sea and one earthquake was able to generate a

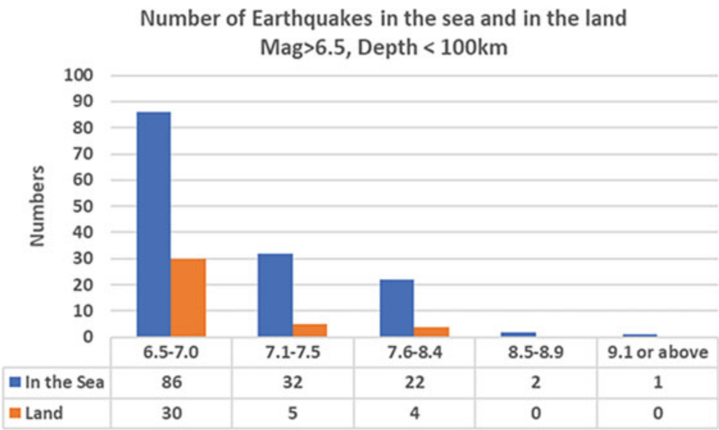


Fig. 12 Categorization of earthquakes for the different magnitude ranges

tsunami in 1945. Therefore, compare with the Indonesian Subduction Zone, Makran Subduction Zone is not active at present.

Figure 12 shows the categorization of earthquakes with magnitude above 6.5 and depth less than 100 km according to the different magnitude ranges in the Indian Ocean and no analysis done for the Makran zone as there were only two earthquakes since 1990.

According to the information mentioned in table three, only 13 historical tsunamis (Local, Regional, and Ocean wide) were generated in the Indian Ocean and the Arabian ocean since 1990. Magnitudes of related earthquakes were above 7.5. Even though the threshold magnitude is considered 6.5, there is only a 17% chance to generate a local, regional, or ocean wide tsunami. Only 25 earthquakes which were above 7.5 magnitudes and above 6.5 magnitudes out of 143 earthquakes were able to generate tsunami events.

As mentioned in the introduction, a regional tsunami can be expected from the magnitudes between 7.6 and 7.8 and the ocean-wide tsunami from the magnitudes greater than or equal to 7.9 in the Richter scale. Based on that earthquakes and generated tsunami (Local, Regional, and Ocean wide) are categorized and the results are shown in Table 2.

The analysis clearly pointed out that the occurrence of earthquakes and possibility of tsunami generation have increased in recent past. During last two decades there are considerable number of tsunami events originated from Indonesian subduction zone and Fig. 13 illustrate the events based on its magnitudes.

For the immediate response, Government of Sri Lanka established National Disaster Management Council to implement policies, Disaster Management Centre to provide early warning, preparedness and mitigation after 2004 Tsunami. However, the national disaster management plan does not specifically talk about the actions needed to take during a tsunami threat. Instead it elaborates about overall disasters in Sri Lanka. Moreover, it clearly mentioned that national operation plans should

Table 2 Classification of earthquakes and its probabilities

Decade	Magnitude	Earthquakes	Tsunamis	Probability
1901–2020	7–7.5	20	1	5.0
	7.6–7.8	12	6	50.0
	7.9 or above	8	5	62.5
2001–2019	7–7.5	11	1	9.1
	7.6–7.8	6	5	83.3
	7.9 or above	6	4	66.7

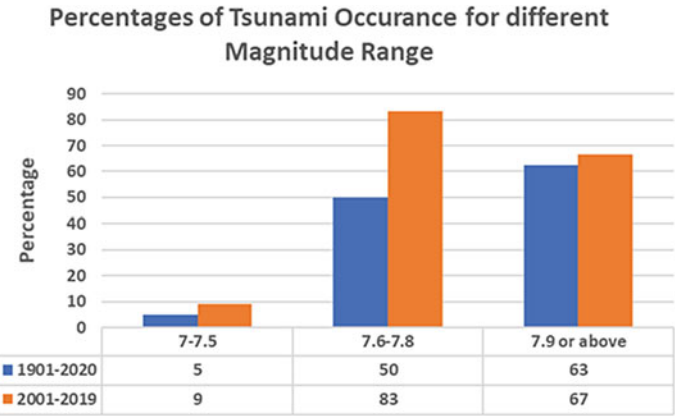


Fig. 13 Tsunami events by its magnitude

be developed with relevant to each disaster along with the coordination of all stakeholders of disaster risk reduction. National Emergency Operation Plan (NEOP) and Standard Operation Procedures (SOP) also prepared with some gaps. NEOP has discussed about all the institutions and their collaborations before, during and after a tsunami event and there are clear instructions given for each institution in Sri Lanka on what actions they should take. Therefore, both national disaster management plan and the NEOP has provided a background to develop specific guidelines and steps during a future tsunami threat.

Sri Lanka has developed Standard Operations Procedures (SOP) for tsunami and there was a synergise SOP illustration the entire process in a single diagram. Recently the authorities have developed the detailed SOP for tsunami and waiting for the approval for implementation. However, all these documents needed updating and currently they are being updated by relevant stakeholders. Therefore, Sri Lanka as a country somewhat prepared for a tsunami even, yet there are several aspects to be improved such as technological capacities, institutional collaboration, monitoring and evaluation.

4 Conclusion

Analysis indicated a slight signal for increasing strong earthquakes in the Indonesian subduction zone with some ups and downs in a long-time span. Generally, the Geological time scale explains in millions of years of scale. Therefore, the sudden trends cannot be expected, however, there were 5 tsunamis occurred due to earthquakes in the Indonesian region during the decade of 2010–2019. It is not a good sign for Indian Ocean countries, especially Sri Lanka. Wave reported at DART 23,401 of the earthquake on 10th August 2009 at the location and distance from the earthquake to DART BUOY is nearly 800 km. The generated tsunami due to the earthquake on 11th April 2012 was also captured by DART 23,227 and 23,401, which are about 670 and 900 km far from the location of the earthquake. Sri Lanka is about 1200 km west of the Andaman Sea, with this information there is a chance to hit a regional tsunami if it will happen in the Andaman trench.

There is a higher possibility to generate local and regional tsunami from earthquakes with moderate magnitudes (Table 1). For such cases, it is not easy to decide where there is a chance to generate a tsunami.

Therefore, lead time to issue a tsunami warning will be short. Considering this situation, it is important to implement some strategies to evacuate people from the vulnerable coastal zones within a shorter time. Establishment of an Information and Communication Technology (ICT) based warning dissemination system until the last mile, and identification of the most vulnerable coastal area with proper evacuation routes are important. Develop infrastructure for vertical evacuation is one solution for the people in such areas. Comprehensive Standard Operation Procedures (SOP) should be developed with a proper time calculation, to decision making and disseminate information until the last mile with considering evacuation time from the most vulnerable locations.

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Analyze and Comparison of the Atmospheric Instability Using K-Index, Lifted Index Total Totals Index Convective Availability Potential Energy (CAPE) and Convective Inhibition (CIN) in Development of Thunderstorms in Sri Lanka During Second Inter-Monsoon

Malith Fernando, Malinda Millangoda, and Sarath Premalal

Abstract Thunderstorm is one of the oldest observed natural phenomena on the earth. Atmospheric instability is one of the important requirements to develop clouds. Therefore, identify and evaluate the relationship of some of the instability indices, favourable to develop cumulonimbus clouds are much important to establish better thunderstorm early warning mechanism. There are numerous instability indices available to assess the instability of the atmosphere for thunderstorm forecasting. Although there are various instability indices which combine thermodynamic and/or kinematic parameters utilized to forecast thunderstorms, effectiveness of these indices for this region have not been studied yet. Considering the importance, this study focuses to identify some instability indices such as K-Index (KI), Lifted index (LI) and Convective Availability Potential Energy (CAPE), Convective Inhibition (CIN), Total Totals Index generate using NCEP FNL, Operational Global Analysis data and correlate it with the observation data,ECMWF's reanalysis data (ERA5) and Lightning Data from GLD 360, for the same region over the Second Inter-Monsoon (SIM) during the years 2015–2017. Results revealed that impact of CAPE and CIN in occurrence in thunder which is a direct outcome of atmospheric instability is very low which is similar with other tropical regional findings, although it is widely accepted for deep convection in the mid-latitude region. Compared to the mid-latitudes, tropical atmosphere is always has a significant amount of energy, but without occurring significant convective activities or thunderstorms. This could be mainly due to the other factors like KI and/or LI which are having higher impact on convection in the tropics than CAPE or CIN.It is evident that the KI, LI, Total Totals Index are good indices for forecasting thunderstorm in the Sri Lankan region during Second Inter-monsoon. This study also showed that the occurrence of thunderstorm in Sri Lanka during Second Inter Monsoon is mostly during the hours of 9–13 UTC

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1 Introduction

Thunderstorm is a natural phenomenon that has been observed by humans from the beginning of times which has caused both good and bad consequences. In Sri Lanka, thundershowers are known to be one of the prime sources of water in the Northern and Eastern parts of the country (with the exception of the North-East monsoon period), (Department of Meteorology, Sri Lanka, 2016). where the majority of the land used for paddy cultivation are located (Department of Agriculture, 2018). Sri Lanka experiences thunderstorms predominantly during the inter-monsoon periods (March to April and October to November) where the solar radiation peaks and the winds over the land are weak. Considering the annual rainfall of Sri Lanka, it could be stipulated that the both inter-monsoon periods contribute to almost 50% of annual rainfall throughout the country (Department of Meteorology, Sri Lanka, 2016). Hence, thundershowers play a pivotal role in enhancing the country's economy and the livelihood of people who engage in agriculture.

Though thunderstorms are strong during the later part of first inter-monsoon, thunderstorms downpours rain throughout the second inter-monsoon season. Compared to the other rainy seasons, SIM is widespread over the country and contribute around 30% of annual rainfall. Department of Meteorology, Sri Lanka, 2016). During this season includes the heavy rains which occur due to the low pressures that established in the Bay of Bengal. These systems are usually developed into depressions and cyclonic storms while giving widespread rainfalls to the southern Indian region (Sreekala et.al 2018) including Sri Lanka.

Moreover, severe thunderstorms can cause extreme destruction in numerous ways as well. Thundershowers have adverse direct impacts on marine, civil aviation and agriculture sectors apart from disrupting day to day activities of the general population. Heavy rains of around 700 mm associated with a mesoscale convective system triggered a landslide in Deniyaya (area in southern Sri Lanka) on 17 May 2003 which caused a loss of around 200 lives (Warnasooriya, 2016.). Heavy intense rainfall with a rate of around 56 mm within 20 min which was a result of thunderstorm caused a flash flood in the metropolitan Colombo resulting in disruption of transport network and economic loss (Warnasooriya et al, 2016). The landslide in Meeriyabadda, Koslanda in Badulla district which happened on 29 October 2014 resulted in 12 deaths and numerous houses being destroyed. This was triggered by rainfall in excess of 500 mm within 3 days of the disastrous event (Somarathne, 2014) which was a result of a thunderstorm (Rupasinghe Premalal, 2016). The above events indicate the magnitude of the damages that thundershowers can cause although they are small in spatial and temporal scale. In Sri Lanka, around 50 deaths are reported annually due to lightning strikes and most of these people were working outdoors (Kumarasinghe, 2008). Majority of these workers are farmers and this has negatively impacted the farming community and the agriculture sector in general.

Thunderstorms are generally considered to be a challenging weather phenomenon to forecast in the current sphere of meteorology. It being small scale spatially and temporally (Perler & Marchand, 2009) and the chaotic nature of the atmosphere makes it difficult to forecast than relatively larger scale phenomena (Elmore et al., 2002). It is a well-known fact that in majority of the instances, forecasters utilise surface observations with remote sense data through satellites and radars to predict thunderstorms in the short term which is widely known now as 'nowcasting'. Experience of forecasting, understanding of local conditions, identifying relevant associated synoptic patterns and climatology (Perler & Marchand, 2009) plays a vital role in correctly predicting a thunderstorm in the current landscape. This timeframe and process is inadequate when the critical nature and the impacts it could cause are considered. Therefore, utilising of instability indices derived by Numerical Weather Prediction (NWP) outputs to determine the possible occurrence of a thunderstorm with a relatively long lead time could be key to better harness the positive effects of a thundershower and also mitigate the detrimental negative effects.

Instability indices have been widely used in the meteorological field to evaluate the instability of the atmosphere which is a fundamental factor in development of thunderstorms. These instability indices are generally a calculated numerical value from various parameters such as temperature, moisture and wind of a vertical column of the atmosphere on a specific location (Ravi et al., 1999). K-Index (George, 1960), Total Totals Index (Millar, 1972), Lifted Index (Galway, 1956) and Convective Availability Potential Energy (CAPE) was used in this study to evaluate the capability the said indexes in predicting thunderstorms.

1.1 K-Index

K-Index defined as;

$$\mathbf{K\text{-}Index} = (\mathbf{T_{850}} - \mathbf{T_{500}}) + \mathbf{D_{850}} - (\mathbf{T_{700}} - \mathbf{D_{700}})$$

where T_{850}, T_{700}, and T_{500} are the temperatures of the 850 hPa, 700 hPa and 500 hPa layers of the atmosphere respectively. D_{850} and D_{700} are dew point temperatures of the 850 hPa and 700 hPa layers of the atmosphere respectively.

It is stipulated that the founders research on K-Index has recognised that the occurrence of thunderstorm probability is 50% when the K-Index value is more than 26 °C (Tajbakhsh et al., 2012). The K-index was primarily used to assist forecasting continental summertime air mass thunderstorm potential (Peppler, 1988). Air mass thunderstorms are typically defined as thunderstorms that develop in areas of weak winds without apparent frontal or cyclonic influence.

1.2 Total Totals Index

The TT Index is comprised of two values: the Vertical Totals (VT) and the Cross Totals (CT). The VT is a measure of the vertical stability without regard to moisture and is found by subtracting the 500 mb temperature from the 850 mb temperature. The CT is a measure of the stability that includes moisture and is found by subtracting the 500 mb temperature from the 850 mb dew point temperature (WFO).

The Total Totals Index (TTI) has been computed by following relation,

$$\mathbf{Total\ Totals\ Index\ (TTI)} = \mathbf{Td_{850}} + \mathbf{T_{850}}$$

where T_{850}, Td_{850} and T_{500} represent 850 hPa levelair temperature, 850 hPa level dew point temperature and 500 hPa level air temperature, respectively (alltemperatures are in °C) (Medha et.al, 2007).

Lal (1989) studied the usefulness of Total Totals Index to forecast thunderstorm activity around Delhi and Jodhpur during March and June and this study reveals that higher values of Total Totals Index correspond to more favourable conditions of thunderstorm activity.

1.3 Lifted Index

Lifted index is defined as the following by J.G. Galway;

$$\mathbf{Lifted\ Index} = \mathbf{T_L} - \mathbf{T_{500}}$$

where T_L is the temperature (°C) of a parcel lifted from 850 to 500 hPa, dry-adiabatically to saturation and moist-adiabatically above that.

Lifted index is a modification of the Showalter Index and strongly resembles it except for the determination of the level from which the parcel is lifted and the use of this index to forecast whereas the Showalter Index is an observed static index (Peppler, 1988). Lifted index was primarily formed as a latent instability predictor in forecasting severe thunderstorms. This index is specified to be extensively used in analysis and forecasting thunderstorms in the United States (Peppler, 1988). In 1956 in Galway's study on Lifted Index (LI), it was given that negative LI indicates that the boundary layer is unstable compared to the mid-troposphere. Galway in his study stipulated that values for LI between −3 and −5 shows marginal instability.

1.4 Convective Availability Potential Energy (CAPE)

CAPE is an indicator of the quotient of energy present for convection. Value of CAPE is directly proportional to the maximum potential vertical speed of an updraft which relates to severe weather occurrence. CAPE is defined as;

$$\textbf{CAPE} = \int_{p_f}^{p_n} R_d(\boldsymbol{T}_{vp} - \boldsymbol{T}_{ve})\boldsymbol{d}\ln \boldsymbol{p}$$

CAPE is indicated as a vertical integration of the parcel-to-environment temperature difference between the Level of Free Convection (LFC) to the Level of Neutral Buoyancy (LNB) which are the levels where the parcel rises freely. It is given that it quantifies the energy a parcel will have when lifted (in J kg^{-1}) and indicates the potential strength of updrafts within a thunderstorm (DeRubertis, 2006). When CAPE is considered, it is recognised that a value more than 1000 J kg^{-1} indicates that the atmosphere is moderately unstable. The atmospheric instability is said to increase with the increase of CAPE.

Meteorologists in various parts of the world uses different threshold values for each of these indices to ascertain the atmospheric instability. The National Weather Service (NWS) of the United States of America utilises the below criteria to evaluate the atmospheric instability for K-Index, Lifted Index and CAPE (US Department of Commerce, n.d.).

KI below 30	Thunderstorms with heavy rain or severe weather possible
KI over 30	Better potential for thunderstorms with heavy rain
KI = 40	Best potential for thunderstorms with very heavy rain

KI denotes K-Index

Forecast	High level TTI
Isolated thunderstorm possible	28–29
Isolated thunderstorm	29–30
Isolated to scattered thunderstorms	31–32
Scattered to numerous thunderstorms	≥33

TTI denotes Total Totals Index

LI over 0	Stable but weak convection possible for LI = 1–3 if strong lifting is present
LI = 0 to −3	Marginally unstable
LI = −3 to −6	Moderately unstable

(continued)

(continued)

LI over 0	Stable but weak convection possible for LI = 1–3 if strong lifting is present
LI = −6 to −9	Very unstable
LI below −9	Extremely unstable

LI denotes Lifted Index

CAPE below 0	Stable
CAPE = 0–1000	Marginally unstable
CAPE = 1000–2500	Moderately unstable
CAPE = 2500–3500	Very unstable
CAPE above 3500–4000	Extremely unstable

CAPE denotes Convective Available Potential Energy

The above threshold values are generally considered to suit any location globally though the suitability of them for different geographic locations are not verified through research. Although research that studies how location, time of day, seasons of the year, etc.affect these threshold values which triggers severe weather events such as thunderstorms are limited, it is accepted that increasing atmospheric instability increases the chance for severe weather. Accordingly, higher values of K-Index and CAPE and negative values for Lifted Index will portray higher instability of the atmosphere. In this context, a set of threshold values were arranged to be tested for this region of interest.

Considering the importance, this study focuses to identify threshold values for some instability indices such as K-Index, Lifted index, Total Totals Index, Convective Availability Potential Energy (CAPE) and CIN in Sri Lankan context.

2 Data and Methodology

Global Lightning Detection database (GLD 360) (Pohjola & Mäkelä, 2013; Demetriades et al., 2010), was opened to the Department of Meteorology by the Finnish Meteorological Institute under the Severe Storm Warning Services for Sri Lanka (SSWSS) project (Fernando et al., 2018). GLD360 was established in 2009. It consists of VLF (Very Low Frequency) sensors worldwide and many evaluations have been carried out against lightning detection systems in the globe over continents (Demetriades et al., 2010; Honoré et al., 2014).

GLD 360 lightening strokes data during the Second Inter Monsoon (SIM) in October and November over the years 2015, 2016 and 2017 was used for the analysis. These data may include both cloud to cloud and cloud to ground strokes with time and location details.

National Centre for Environmental Prediction (NCEP) FNL (Final) is a 0.25 × 0.25-degree resolution Global Tropospheric Analyses and Forecast Grids data, which are generated on a six hourly basis under Global Data Assimilation System (GDAS). This system collects observational data from Global Telecommunication System (GTS) and other sources over the globe. The data are available from July 2015. Analysis data from NCEP FNL were used for this study to calculate indices related to thunderstorms as K-Index, Convective Available Potential Energy (CAPE) and CIN.

ERA5, reanalysis from the ECMWF. This is the fifth generation of reanalysis data from ECMWF. Data available from 1979 at the moment, however ECMWF will extend it to the 1950 eventually. Similar to other reanalysis data, ERA5 data also uses the observation data over the globe and grid them hourly using 4D Var data assimilation. Instability indices such as K, CAPE, Totals and CIN were extracted from the ERA5 hourly data over the study period.

Inter-monsoon periods of consecutive years from 2015 to 2017 were selected as the study period. The number of observed total strokes in Sri Lanka by the GLD360 during the study periods are as follows.

	2015	2016	2017	Total
October	507,845	209,431	424,473	521,476
November	135,097	205,048	181,331	1,141,749
Total	642,942	414,479	605,804	1,663,225

All the observations were plotted with respect to their observation hour during the day searching for basic statistics i.e. strokes time of the hour during SIM.The spatial map of stroke frequency percentiles was plotted to observe the spatial distribution of all the thunder during aforementioned three years in Sri Lanka. This map was plotted using percentiles of which the number of strokes observed in each grid in the spatial map, during all the three year's SIMs, with respect to the total number of strokes of all three years of SIM strokes. ERA5 and NCEP reanalysis data were extracted based on observed strokes locations and times. Extracted reanalysis data were plotted as histograms and spatial maps. Causes were searched for the strokes/thunder activity during SIM period using few of the reanalysis parameters such as lower level winds and vertical divergence.

3 Results and Discussion

Figure 1a shows the number of thunder flashes during the Second Inter-monsoon season and Fig. 1b shows the spatial distribution.

According to the Fig. 1, it can be seen that there is a peak time of strokes/thunder during the day which is around 9–13 UTC. Observed thunder activities are minimum during the other times of the day. Figure 1b indicated the higher possibility of thunderstorms around the Central hills with highest over the western part.

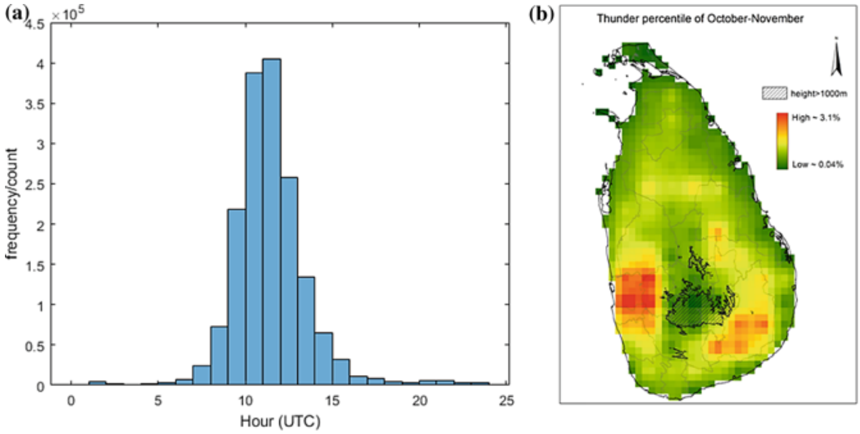

Fig. 1 **a** GLD 360 Strokes observation time (hour UTC) versus number of strokes in Sri Lanka during SIM. **b** Spatial distribution of percentile of observed strokes from GLD360 in Sri Lanka during SIM. The land higher than 1000 m are shaded.

The spatial map of strokes percentile shows a very higher stroke percentiles over the western parts of Sri Lanka, Particularly Gampaha, Colombo and Kegalle districts and in Monaragala districts which is located I the South-eastern part of Sri Lanka. Compared to the other areas, central highlands and Northern and Eastern coastal areas have the minimum strokes percentiles.

Sea breeze during the day time with the more heating of land during inter monsoon periods are more prominent. Due to convectional current and orographic effect, more thunderstorms develop around the hills. Second Inter-monsoon starts just after end of southwest monsoon. Monsoon winds are not suppressed suddenly along the island as it is a regional feature (Fig. 2). Therefore, weak southwest monsoon current

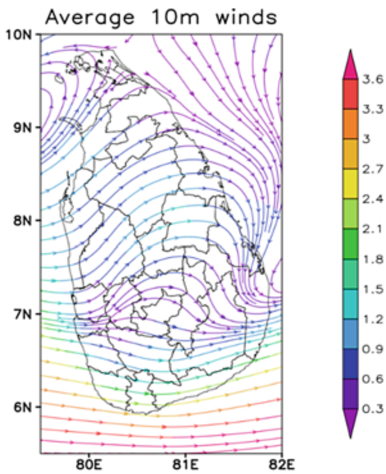

Fig. 2 Spatial distribution of averaged 10 m-wind stream lines (m/s) values from ERA5 data in Sri Lanka during SIM over the period 2015–2017

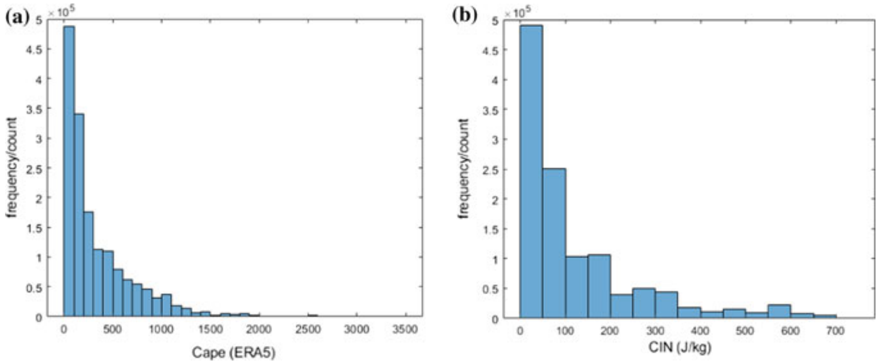

Fig. 3 **a** CAPE (J/kg) values extracted from ERA5 data versus number of observed strokes from GLD360 in Sri Lanka during SIM. **b** CIN (J/kg) values extracted from ERA5 data versus number of observed strokes from GLD360 in Sri Lanka during SIM

will provide more moisture to inland areas compared to the other parts. Therefore, generally more thunderstorms occur along the western part of hills compared to the other parts.

Spatial distribution of average 10 m winds in SIM during the years 2015–2017 shows wind convergence over the land in south-eastern parts and western parts particularly, Colombo Kegalle and Monaragala districts. On the other hand, wind speed also very low. Both of these facts support the occurrence of thunderstorms.

Figure 3a shows the CAPE and Fig. 3b is CIN distributions of observed strokes in Sri Lanka during the study period. It depicts that CAPE and CIN values which are related to the strokes do not follow the generally accepted behavior which could be normal distributions with a peak. It seems like CAPE and CIN are not much affect over the observed strokes.

According to the Fig. 4, K-index distribution of the observed strokes are mostly normally distributed with KI values. It can be observed that the most of the strokes are having the KI values greater than 25 and less than 39 which is acceptable for thunder activity. Figure 4b shows the spatial distribution of KI values. Minimum values for K-Index are observed over the Central hills of the country. Western Southern and Eastern parts of land show higher K-Index values.

Figure 5a shows, NCEP extracted four-layer Lifted Index values distribution for the corresponding strokes are more like a normal distribution with its frequencies. It shows almost all the extracted values are negative and greater than −6 which is in general good instability condition for thunder activities in the region. Figure 5b shows spatial distribution of LI.

Figure 6 shows Total Totals Index value distribution is seeming like a bell-shaped distribution and the values are accumulated in between around 39 and 47. This condition is also favorable for thunder activities and at the same time literature suggest higher than 44 for thunderstorms. Averaged Total Totals Index (TTI) is showing a similar behavior as the K-Index map. The minimum index values are accimilated

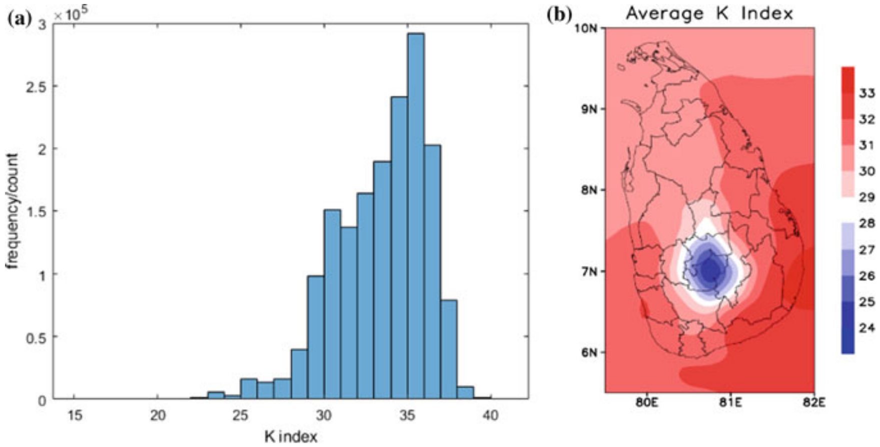

Fig. 4 **a** K index (0C) values extracted from ERA5 data versus number of observed strokes from GLD360 in Sri Lanka during SIM. **b** Spatial distribution of averaged K index (0C) values from ERA5 data in Sri Lanka during SIM over the period 2015–2017

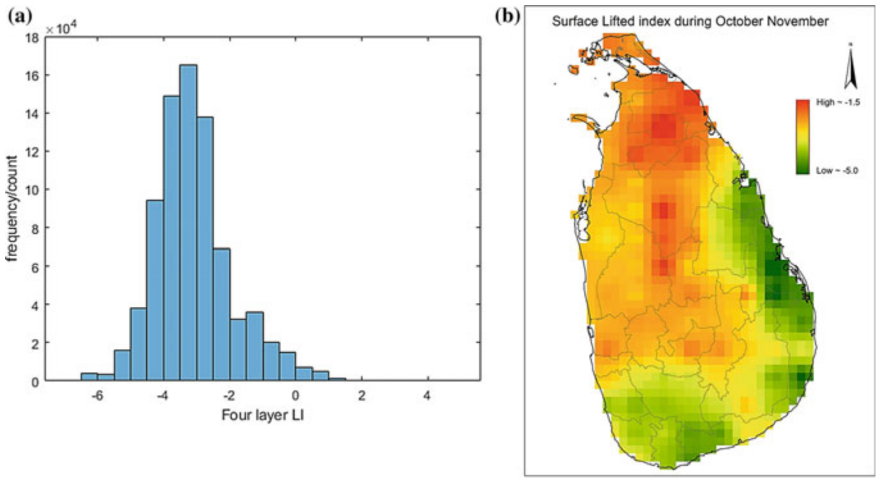

Fig. 5 **a** Four layers lifted index (°C) values extracted from NCEP FNL data versus number of observed strokes from GLD360 in Sri Lanka during SIM. **b** Spatial distribution of averaged lifted index (°C) values from NCEP data in Sri Lanka during SIM over the period 2015–2017

over the central hills while the other areas have comparetively higher TTI values (Fig. 6b).

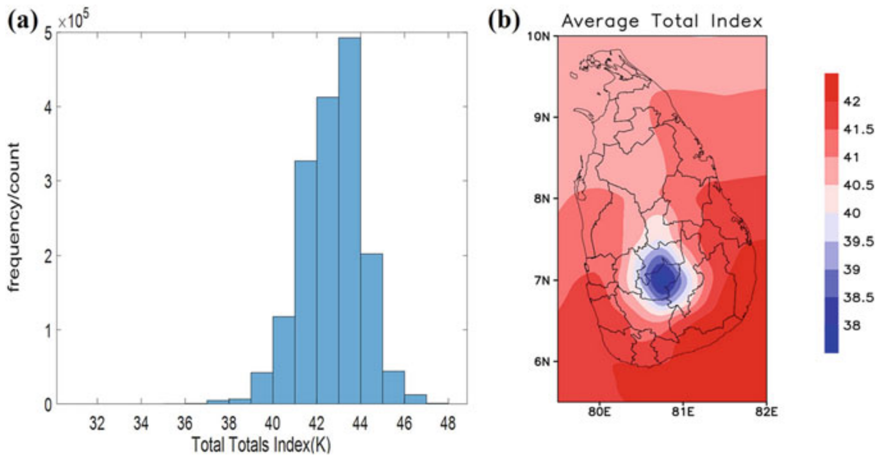

Fig. 6 **a** Total Totals Index (0C) values extracted from ERA5 data versus number of observed strokes from GLD360 in Sri Lanka during SIM. **b** Spatial distribution of averaged Total Totals Index (0C) values from ERA5 data in Sri Lanka during SIM over the period 2015–2017

4 Conclusion

In this research we identified and evaluated the relationship of some of the instability indices which are playing vital role to develop cumulonimbus clouds and important in understanding the behaviour of thunderstorms.

Analysis clearly indicated the importance of instability indices for thunderstorm prediction. Except CAPE and CIN, all the other indices pointed out the global threshold values. Generally, it is accepted that CAPE values should high to develop thunderstorms. As some researches suggest, CAPE values have no higher impact in developing thunderstorm in tropics. Similar situation is observed in the research area, which the thunderstorm could be developed even with low values for CAPE in SriLanka.

This study also showed that the highest chance of occurrence of thunderstorm in Sri Lanka during Second Inter Monsoon period is mostly during the hours of 9–13 UTC. This would help forecasting thunderstorm in the future.

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Command and Control Mechanism for Effective Disaster Incident Response Operations in Sri Lanka

H. I. Tillekaratne, D. R. I. B. Werellagama, and Raj Prasanna

Abstract Effective disaster response is one of the biggest challenges to all governments worldwide. Centralized governance system has been identified as not ideal for effective disaster response. For Sri Lanka, 2004 tsunami was a milestone for the evolving change in the national disaster response mechanism. However, the inadequacy of the existing response mechanism to disasters in Sri Lanka was seen during recent island wide repetitive disaster incidents. This study explores the evolution of "disaster response" mechanism in Sri Lanka from 2004 tsunami situation. A detailed study is carried out through expert interviews and literature based findings providing suggestions to improve existing command and control structure, comparing with some of the international best practices such as Search and Rescue (SAR) Groups and Coordinated Incident Management Modality (CIMM). The developed response framework allows personnel from a variety of civil and military agencies to meld rapidly into a common management structure, by providing logistical and administrative support to the operational staff. The prospective model for efficient disaster response operations will address the need of an integrated response framework to guide the risk response planning process in Sri Lanka.

Keywords Disaster-response · Command-control · Incident-command-system · Search and rescue (SAR)

1 Introduction

Disasters are by nature dynamic, emergent scenarios including diverse stakeholders in complex decision making and as such, disaster response systems must account

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for these conditions (Bunker et al., 2015). Studies have proved that disasters cause proportionately more damage to developing countries and poor communities. Future estimated impacts of disasters for the period 2020 to 2030 suggest that people in Asia–Pacific region will endure 40% of the total worldwide future economic losses from disasters, majority of the fatalities, and other losses. Amidst those countries with special needs, developing countries like Sri Lanka, can suffer the loss of almost 4% of GDP due to natural disasters (Munasinghe & Matsui, 2019). Sri Lanka, an island nation, with tropical climatic conditions is highly prone to natural hazards such as floods, landslides, droughts, cyclones, high winds, lightning strikes, forest fires and urban fires.

Effective disaster response poses one of the biggest challenges to all governments worldwide whereas centralized governance system has been identified as not ideal effective disaster response (Malla et al., 2020). The 2005–2015 Hyogo Framework for Action (HFA) and 2015–2030 Sendai Framework for Disaster Risk Reduction highlights the need of decentralized approach for effective disaster response (UNISDR, 2015). Ideally, response mechanism should be based on the four pillars of Sendai Framework for Disaster Risk Reduction, (SFDRR) by understanding Disaster Risk; strengthening governance to manage Disaster Risk; investing in Disaster Risk Reduction for Resilience and enhancing disaster preparedness with Early Warning system for effective response to "Build Back Better" in Recovery, Rehabilitation and Reconstruction (Amaratunga et al., 2020).

Since disaster response is a bottom up approach, local level disaster response mechanism is the fundamental pillar for decentralization. As local authority and the local community should respond immediately to a disaster, their effectiveness is crucial. In that sense, their competency plays a critical role to save lives and properties at the time of disaster. A Command and control structure includes communication (both vertical and lateral), information management, resource management and first responder/SAR-Technicians coordination. The information usually flows up the hierarchy, while the commands flow down the hierarchy. With increased communication, uncertainty could be reduced, and disaster response becomes more efficient (Chaudhury et al., 2012).

Looking at the Sri Lankan scenario, it could be seen that an integrated response framework is needed to guide the risk response planning process and implement preventive and corrective actions to avoid, reduce and transfer the risks. At the point of 2004 Indian Ocean earthquake and tsunami, Sri Lanka did not have a formal institution with overall responsibility, nor regulatory mechanisms for managing disaster and emergency situation (Disaster Management Centre (DMC), 2014). Therefore the 2004 tsunami could be identified as a turning point which induced a system change with the introduction of the Disaster Management Act in Sri Lanka (Sebesvari et al., 2019). The legislative intent of the DM Act was to, "*provide for the effective management of disasters*". Since 2010, some attention was received in the arena of Disaster Risk Reduction and mitigation efforts, however a systematic disaster response mechanism was not developed at this stage (Disaster Management Centre (DMC), 2014). Hence it is important to trace the available Disaster Response process, to investigate the applicability of success stories and practices worldwide, for effective and efficient domestic incident management. The inadequacy of the existing response mechanism to disasters in the Sri Lankan context is reflected through the island wide repetitive disaster incidents. For example, in May 2017, heavy rainfall resulted in severe floods and landslides affecting 15 out of 25 districts in Sri Lanka. In total, 200,382 people were affected, 100 human lives were lost and 99 were missing (Munasinghe & Matsui, 2019). Other examples are floods and landslides in May 2016 accounting for 101 deaths with 100 people missing and Collapse of *Meethotamulla,* Colombo Municipal Solid-waste dump in 2017 with reported 32 deaths and 8 persons missing.

To achieve a resilient community at large, both soft-measures and hard measures in disaster management process should support each other. Every disaster occurrence opens up a spontaneous research ground to test these measures and deciding factors for the level of the response mechanism and deployment.When such massive disasters occurred, "Responders" were dispatched to the affected area and later organized as a Joint Task Force. A gap was identified—due to non-availability of a legalized response framework, the scope and multi-sector authority were not regulated within a pre-determined mechanism. Another challenge was issuing of specific Early-Warning messages by the DMC at national level, referring to different general Early-Warning (Advisory/Watch/Warning/Alert etc.) Bulletins of Technical Agencies (e.g. NBRO, Meteorological Dept., Irrigation Dept.).

There are two interdependencies of emergency response management: government/ municipal and community responsibilities. However, community involvements, are often ignored in both proactive (Risk-Management) and reactive (Crisis Management) situations. Observing spheres of DM cycle (Fig. 1) suggests strong modes of communication should be established to bridge this gap.

This chapter explores the evolution of "**disaster response**" mechanism in Sri Lanka from 2004 tsunami situation. It further aims to provide suggestions to improve existing command and control structure, comparing with some of the international best practices.

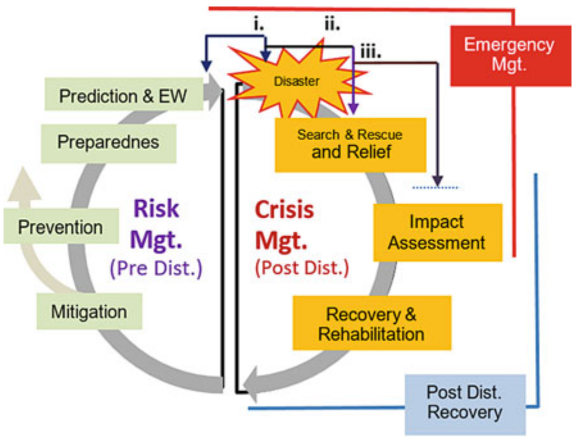


Fig. 1 The spheres of disaster management cycle. (i) pre-incident, (ii) during the incident, (iii) early recovery stage

2 Methodology

A detailed literature survey was carried out to investigate the evolution of Command and Control mechanism and various initiatives to improve the disaster response mechanism in Sri Lanka and elsewhere. Success stories and best-practices (worldwide) were discussed to explore the research and operational knowledge gaps.

Seven semi-structured interviews were conducted with key Incident Command System (ICS) National Trainers and stakeholders from government agencies (including Divisional Secretaries) to map the gaps (missing links) and suggest suitable response mechanisms. Interviews were transcribed and thematic analysis was conducted, allowing key themes to be identified. These data were complemented with further in-depth literature review. Initiatives taken to establish response management mechanisms, such as ICS and related specific response systems were evaluated by Key Informant Discussions.

Efforts for the establishment of integrated SAR group and establishing a national standard for SAR Training Curriculum, were evaluated against the INSARAG USAR curriculum at SAR training Schools in Sri Lanka (Special Forces Training School-Maduruoya, Special Task Force Training School–Katukurunda, Fire And Rescue Training Academy (FARTA) Wellawatta and Sri Lanka Army Center for Disaster Response Training (SLA-CDRT, Gampola), and Rapid Action Boat Squadron Training School (RABS-TS, Puttalam), Sri Lanka Navy).

3 Results and Discussion

3.1 Disaster Response Timeline After Asian-Tsunami (Dec. 2004–2019)

In Sri Lanka, post-tsunami response led to coordination of all donor assistance, fundraising and other financing aspects through the hurriedly assembled "*Task Force for Rebuilding the Nation (TAFREN)*". Reactive response to disasters was the main approach to disaster management. The policy framework was fragmented and responsibility of disaster risk management, Early-Warning, Rescue and Relief etc. were scattered among various institutions.

Such limitations led the government to introduce the legal framework for Disaster Management by enacting the Disaster Management Act No. 13 of 2005 (Disaster Management Centre (DMC), 2006, 2019). This Act allowed moving towards a new paradigm with a proactive approach to disaster management. Consequently, the Disaster Management Centre (DMC) was established. The DMC lays down policies, plans and guidelines for management of disasters. District Disaster Management Coordination Units (DDMCU) were established to work in coordination. Nine DDMCUs were initiated (staff seconded from Tri-Forces (Army, Navy and Air force) and STF (Special task force of Sri Lanka police) in September 2005, under the purview of the National Council on Disaster Management (NCDM) chaired by the President (Disaster Management Centre (DMC), 2006a, 2014, 2019). In order to achieve all these, the President could exercise all powers of NDMC ensuring adequate political and constitutional heft behind the decisions made during hazardous and emergency situations.

The DMC mandates include activities associated with disaster Mitigation, Preparedness, Dissemination of Early warning, Emergency operations, Coordination of Relief and Post Disaster Activities. DMC's role was limited to operate as a Coordinator and a Facilitator, but rarely as an implementer (Disaster Management Centre (DMC), 2014). In 2006, an Emergency Operations Centre (EOC) was established at DMC which functions on a 24 × 7 basis. The EOC receives, analyzes, and displays information, coordinating activities related to all incidents to ensure an effective and coordinated response in an emergency. The EOC also finds, prioritizes, deploys, and tracks critical resources, coupled with 24 × 7 Call-Centre which coordinates resources to the sub-national/grass-root levels (Disaster Management Centre (DMC), 2006b).

3.2 Disaster Response Coordination

Command and control structure from the national level to village level (top-down) involves several officials, as shown in Table 1. National level stakeholders are mandated to respond to disasters according to the roles and responsibilities stipulated in the National Emergency Operation Plan **(NEOP)** and respective Institutional Disaster Management Plan **(IDMP)**. The system is evidently inefficient, due to not having dedicated response persons, limited working hours and missing links in the handing over/taking over from the military-responders.

3.3 Emergency Response Coordination C4-SAR

In 2004 December, within the first 24 hours of the Asian-Tsunami, Centre for National Operations (CNO) was established under the President (Chief Executive) to coordinate both national and international relief operations. The CNO, provided the essential interface between concerned government ministries, local authorities, the military, and the international assistance community (Yamada et al., 2006).

In 2005, with the establishment of the DMC, Emergency-Response Activities were coordinated through the Emergency Response Committee (ERC). Accordingly, all relevant SAR-Technicians and Essential Services needed to be coordinated, to work together at the national level, during a disaster. Later, ERC activities were covered by the two annual Monsoon Response Meetings (Forums). To strengthen the disaster

Table 1 Chain of command and control hierarchy in DM—Sri Lanka

Response level	Official	What they do and with whom
National	EOC-DMC	Interacts with both District Unit and Media for timely dissemination of warning to vulnerable communities and to responding agencies
	The Office of Chief of Defence Staff (OCDS)	Ensures deployment and support of the Tri-Forces and the Police for effective emergency response
District	District Secretary, leads (DDMCC)	Lead role with District level stakeholders, leading the respective District Disaster Management Coordinating Committee (DDMCC)
	Politicians (MPs)	Involved in the decision-making process at Provincial/ District level
Division	Divisional Secretary	Coordinates with respective Local Authorities (Municipal and Urban Councils & *Pradeshiya-Sabhas*) and NGOs for resource sharing
	Local politicians	Involved in the local decision-making process
Grassroots	*Grama-Niladhari* (Village-Officer)	Interacts with the village DM Committee and stakeholder representatives, Community Based Organizations (CBOs) and private sector organizations to respond to disasters and obtain direct support to vulnerable communities

warning and response chain, all key stakeholders reliable in SOPs (Standard Operating Procedures) assure that each response is consistently functioning in possible efficient manner (Haigh & Amarathunge, 2018).

In 2017 December, Command, Control, Coordination and Communication-Search & Rescue Teams (C4-SAR) Committee was established under the Secretary of the Ministry, by adding specific responsibilities and lessons learnt from ERC, integrating personnel, procedures, equipment and communications, operating within a common organizational structure.

C4-SAR aims to efficiently respond to any incident, with objectives of C4-SAR being: to coordinate rapid deployment; monitor and evaluate the operational effectiveness; make recommendations to improve the efficiency of SAR operations and obtain equipment and specialized training to enhance the capacity of SAR teams. Separate Terms of Reference (ToR) for the committee and three documents (namely, institutionalizing C4-SAR Committee; standardizing SAR Training and provision of SAR Equipment) were approved in December 2017 and May 2019. Committee members are shown in Fig. 2 and its organizational structure is shown in Fig. 3.

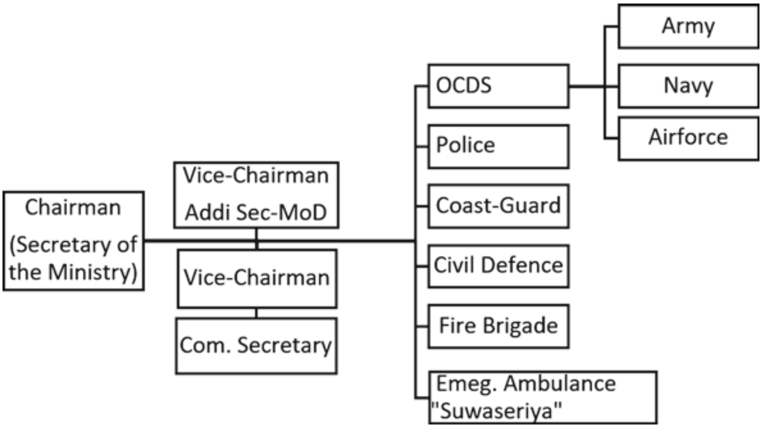


Fig. 2 Members of the C4-SAR committee (Sri Lanka)

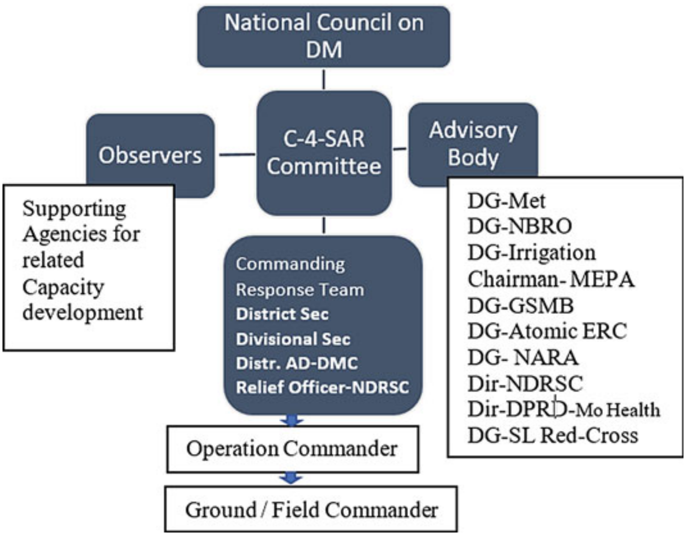


Fig. 3 Organizational structure of C4-SAR committee (Sri Lanka)

3.4 Global Best Practices and Their Applicability in Sri Lanka

Search and Rescue (SAR) Groups

After the World-War-II, the paradigm of Rescue-Team and Civil Defense was brought back under the Community Emergency Response Teams. Several civil defense organizations changed their cognitive focus providing rescue services during natural disasters (e.g. State Emergency Service in Australia, CERT in USA) (Norris et al., 2008). A similar system was introduced with the "Civil Security Committees" during the civil war in Sri Lanka and use of such community groups along with formal disaster response units, must be further explored.

International Search and Rescue Advisory Group (INSARAG) established in 1991, under the United Nations umbrella; promotes the exchange of capacities between national urban SAR organizations. INSARAG External Classification (IEC) serves as a tool, ensuring all international Urban-SAR (USAR) teams acquire minimum operational standards (Okita & Shaw, 2020). Table 2 describes the selected SAR-Technicians and operational mechanism.

Incident Management (international practice)

In response to cases of disaster and emergencies, National Incident Management System (NIMS), is a comprehensive approach applied in emergencies of all types and sizes. Incident Command System (ICS) model for incident management, applied during 1970s wildfires in California (USA) became a national response mechanism in the USA and several countries (FEMA, 2017). ICS does not create a universally applicable bureaucratic organization among responders, rather a mechanism for inter-organizational coordination. ICS enables the five major functional areas (Operations, Planning, Logistics, Finance and Administration), led by five team leaders. The entire system is led by an Incident Commander (Buck et al., 2006). This system envisages that roles and duties shall be assigned (known) in advance, with personnel earmarked and trained in their respective roles and duties. Different countries have their own ICSs; Australasian Inter-Service Incident Management System (AIIMS) in Australia and Coordinated Incident Management System (CIMS) in New Zealand and Incident Response System (IRS) in India.

4 Recommendations for Improving the Disaster Management in Sri Lanka

4.1 Coordinated Incident Management Modality (CIMM)

The CIMM defines various tasks to be performed by the available administrative machinery at various levels. Officers for the performance of different tasks should be pre-identified. They should be trained in their respective roles and tasks, under which all the line-departments must function in tandem with the District and National administration, like the well-tested elections process (operating country-wide). Based on the analysis, Fig. 4 presents a CIMM model for the Sri Lankan Disatser Management System.

Table 2 Groups of SAR-Technicians in selected countries (Adachi & Bureau, 2009; Okita & Shaw, 2020; Yoon et al., 2016)

Country-SAR-technicians	Organization/deployment	Command and control mechanism
The Republic of Indonesia—National Search and Rescue Agency (BASARNAS) IEC-classified team	SAR Coordinator—(Head-BASARNAS), SAR-Mission Coordinator (S-MC) and On Scene Coordination (OSC) to control SAR Unit, (military, police, Red-Cross, NGOs.)	S-MC's staff handling operation, administration & logistics, communication, intelligence and public relations
Japan—Fire and Disaster Management Agency (FDMA) Disaster management activities and Emergency response	Closely linked to local communities and active in specialities including emergency rescue handling of hazardous materials and firefighting	Technical Emergency Control Force (TEC-Force), join with FDMA to provide fast technical assistance-damage assessment, fast restoration in large-scale disasters
India—National Disaster Response Force (NDRF) (established under Disaster Management Act, India, 2005)	Apex Body for DM, National Disaster Management Authority (NDMA) direct for the purpose of specialist response	Incident Response System (IRS) by the NDMA, Central Government assistance to the affected state, including deploying of Armed Forces, Central Paramilitary Forces, NDRF and other assets
Sri Lanka, depending on the scale/type of a disaster, the military take the responsibility of SAR missions in general	Fire-fighting units for fire responses and C4-SAR related rescue missions	No proper binding mechanism between SAR units and the DM authorities and this chapter suggests Coordinated Incident Management Modality (CIMM)

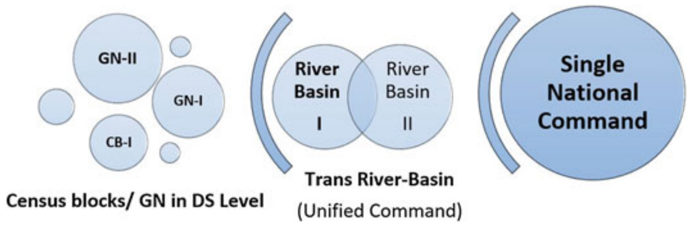


Fig. 4 Affected groups expanding from community based response areas

Census-Block (CB) up to National level with the intensity of the Incident,. Households 1–5 < 80–100 Households (Census-Block) < Grama-Niladari (GN) Division< Divisional Secretary (DS) Division < District Secretary (DS) Division < River-Basin.

C4-SAR Committee leads to the establishment of a joint dedicated SAR-Force, comprising of SAR Teams members/Technicians from Army, Navy, Air-force, Police and Fire-Departments (which like BASARNAS of Indonesia) conduct SAR duties in Sri Lanka under the command of C4-SAR by fitting to Coordinated Incident Management Modality (CIMM). As every individual step is crucial in every emergency, the whole cycle of DM must always be considered through the CIMM.

4.2 Deployment of Search and Rescue (SAR) Teams

There are about 9316 formal SAR Members/Technicians in Sri Lanka apart from the General Units of the Tri-Forces. To-date the dedicated SAR Teams and special response units are as follows. SL Army (*2250* SAR and Immediate Response-IR, *575*), SL Navy (Rapid Respond Rescue Relief 400) Total *1700*, SL Air-force (*720* at bases and Regimental Special Force-RSF *61*), SL Police Total (50 × 50 Police Divisions) *2500,* Fire Departments *925* Fire-fighters, Emergency Ambulance—"*Suwaseriya*" *585* Emergency Medical Technicians). Team deployment concept has showed positive results in Sri Lanka emergency situations. Also, Sri Lanka Coast Guard and Civil Defense Department provided support services for the SAR missions.

There were several initiatives taken to initiate specialized response teams. Regimental Special Forces (RSF), Special Boat Squadron (SBS) and Specialized Rapid Response Team are such key trained units for effective response in emergencies such as oil-spills, hazardous chemical and industrial accidents and Radiological emergencies etc. Under the DM Act, the Council and the DMC shall be assisted by several Technical Advisory Committees (TAC) consisting of professionals and experts on the respective functions and responsibilities (E.g. CEA mandated agencies for Chemical Accidents). Like TEC-Force in Japan (Table 1), a Rapid-Technical Field Response Group, is to be formed to deploy with SAR-Technicians on the different terrains and circumstances.

Committee on C4-SAR (Fig. 2) maintains the unity of command and direction by providing a common hierarchy amalgamating different SAR groups at operational level to achieve the tactical objectives. Yet a modality for broader application of emergency responses in Sri Lanka is still needed.

4.3 Response Time and Sphere

Response time is very critical in emergency operations as more trapped time, leads to more deaths and casualties, as shown in Fig. 4. Considering the Golden-Hour principle, SAR technicians should act within 8–12 minutes to rescue the critically injured. The fatality rate is 50% if response time is three minutes after a cardiac arrest and ten minutes after a respiratory-arrest. Survival in out-of-hospital cardiac arrest significantly depends on the period until the initiation of cardiopulmonary resuscitation (CPR) (Dynes, 1990; Organization, 2010).

Considering the time scale during a disaster for three consecutive STAGES (Pre, During, After) of the incident, three different management techniques and three different approaches could be utilized as depicted in Fig. 5.

SAR efforts are chronological and continuous, representing all levels of response, starting with spontaneous community actions (self-help within a few minutes and, mutual-help by neighbours) immediately following the disaster. Therefore, it is essential all the SAR-Technicians have appropriate equipment and capacities and recognize community volunteer link to the Coordinated Incident Management Modality CIMM.

Disaster response initiated by local emergency services and rescue efforts continue with the arrival of national rescue resources after few hours. International rescue teams respond in few days after the incident following an official request by the government (Fig. 6). In Japan, during a disaster situation, it is estimated that 70% is self-help, 20% mutual help and 10% Public and Government engagements (Adachi & Bureau, 2009). After a disaster (as shown during the recovery from Hurricane Sandy in 2012, in the USA), the community was encouraged to take care of itself during the first 72 hours (Dynes, 1990).

Community Engagement should be linked with the emergency responders, as all the survivors are first responders, rather than "victims" (Van Krieken et al., 2017). Funeral-Aid (*Maranadhara*) Societies are a social capital resource in Sri Lanka, with strong networks that may work to improve the resilience of a community, through voluntary Mutual-help. Chronological response framework can be legalized

Fig. 5 Risk in emergency response phase

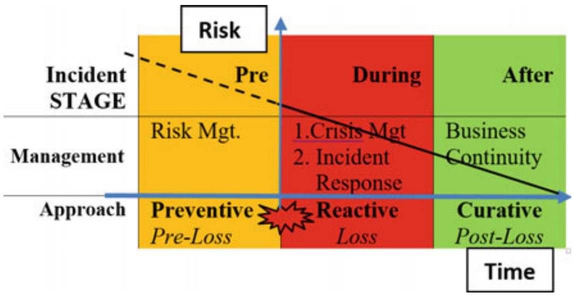
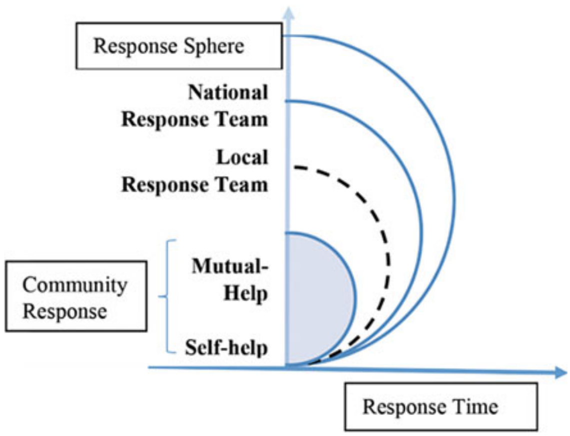


Fig. 6 Chronological response framework-change of the incident response sphere with temporal dimension



by giving responsibilities in overall disaster response system through CIMM. Accordingly, the building of a resilient society is a collective outcome by the government and the community concerned.

4.4 *Civil-Military Relationship*

Cooperation between civilian and military authorities is crucial for the success of operations in complex situations. In this process, communities/local people, create organizational linkages, boost and secure the social support during unplanned incidents, which requires flexibility, decision-making skills and trusted sources of information that function in the face of unknowns (Yamada et al., 2006).

Disaster response is usually a spontaneous process and experience confirms that an effective humanitarian response at the onset of a disaster is heavily influenced by the level of preparedness of communities and a broad range of tasks or skills of responding agencies (Disaster Management Centre (DMC), 2014). The term "command & control" very much reflects a top-down perspective and a military approach. The humanitarian-civilian approach is built on a "bottom-up" perspective, which is more cooperative in its nature. Every military disaster response operation has a humanitarian consequence and cooperation between civil-military authorities facilitate better coordination. As both groups need to use the same resources, joint development of contingency plans are needed for military support to humanitarian tasks (such as SAR operation and protection of warehouses and key facilities) (Malešič, 2015).

When the DMC requests, C4-SAR committee will direct the combined SAR Team to the disaster incident and a proper Incident Management Modality must be incorporated into the system with different SAR response agencies, including essential-services and the community. To ensure interoperability between different levels of response, it is vital to provide a common platform regardless of the different systems for command and control at the operational level. Regulations should be enacted to legalize ICS as standard response/operational tool, with some modifications and adaptation to the Sri Lankan context. Accordingly, it is suggested to introduce a response modality namely Coordinated Incident Management Modality (CIMM), by facilitating Civil-Military (SAR Teams commanded by C4-SAR) agencies helping each other.

4.5 *Risk Transfer Levels*

When the response of the incident exceeds area capacity (e.g. Divisional Level), it is supposed to be escalated to the next area response level, until the colour gets green. Accordingly, the risk level will be communicated through a risk value legend by marking a risk profile map. E.g. At Divisional Level. **Low** (*Green)* $\geq$4; **Moderate** *(Amber)* 4<, $\geq$5; **High** *(Red)* 5<, $\geq$6 (Fig. 7). Accordingly threshold for the response level should be identified for each disaster.

The DMC is mandated to coordinate the Three Levels of Disaster Response efforts with responsibilities pertaining in Standard Operating Procedures (SoPs).

- **Level** I: Agency/community contains the incident and respond using its own resources. E.g. Minor Fire
- **Level II**: Requires assistance beyond Division up to Province. E.g. Flood.
- **Level III**: exceeds the capacity of the Province and requires assistance from the national or even international level. E.g. Tsunami/ Earthquake.

Availability of an emergency response mechanism ensures that resources are directed to areas in most need. All individuals need to learn skills for mass rescue and emergency treatment as well as the location, structure and functions up to the expanded national ICS (Yamada et al., 2006).

Different levels of command clarify the different working levels on consecutive time scales which need to be adopted as an integrated structure, to match the complexities and demands of dynamic incidents. Problems arising during the process need to be solved within a shared model of command, at the operational and strategic

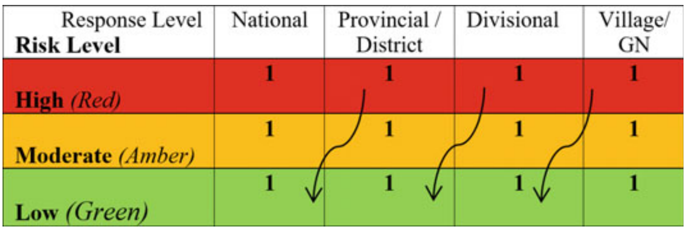


Fig. 7 Risk transfer-model for each response level

levels. Accordingly, Strategic and Operative commands must be separated during operations in major emergencies (Malešič, 2015).

4.6 Establishing the Response Mechanism

Clause 11 of the Disaster Management Act (Sri Lanka) says, if the severity of a disaster or impending disaster is likely to be so great, beyond the capacity of the available resources, then the President (as the head of the National Council for Disaster Management-NCDM) may declare a State of Disaster for the affected area or the whole country. Upon the declaration, the President shall direct any appropriate organization/s like (Disaster Management Centre-DMC) to take immediate action to carry out and activate the NEOP (National Emergency Operations Plan), as the case may be, and generally assist the NCDM in the discharge of its functions.

A similar well-tested mechanism exists in Sri Lanka during the declaration of an Election and Department of Elections has been carrying out these procedures since 1955. The Commissioner of Elections is answerable only to the judiciary and has been vested distinct and unique independence which is exercised by no other government department. If such a widely utilized and familiar model could be rapidly adopted as the legal/ institutional framework for Disaster/Incident Response system, it will be very effective. Due to the familiarity of the system the same process converted to disaster and emergency situations will result in effective disaster response.

Although the Sri Lankan military is accustomed to handling emergencies through their command structure, the overall response system was inefficient without a formal incident command system (Yamada et al., 2006). As a professional incident management tool, DMC in partnership with the USAID, conducted an Intermediate Training Module on ICS for the District officials (with 30 National Trainers) during 2008 to 2012. According to the results and the feedback it is clearly evident that, a Coordinated Incident Management Response Modality must be established replacing the present ad-hoc response systems.

Under subsection one, of the Disaster Management Act, an appropriate organization is designated by the council and specifies the area(s) in which each such organization, shall carry out its implementation activities. Marine Environment Protection Authority (MEPA) of Sri Lanka adopted ICS (through National Oil Spill Contingency Plan-NOSCOP) to respond at a national level oil spill. Such experiences are useful when adapting the CIMM at National Level. Accordingly, as a long-term strategy, regulations should be established to recognize CIMM as the standard response management tool.

5 Conclusion

This chapter discussed the evolution of disaster response in Sri Lanka, with reactive response following the 2004 December Tsunami, to date. Furthermore, the discussion was focused on aligning international best practices to the current system, to uplift the disaster response mechanism in Sri Lanka. Also the command & control structure was explained and communications hierarchy was identified through the committee on C4-SAR. The gaps identified clearly demonstrate the need to go beyond SAR opearions and establish a broader application of emergency responses modality in Sri Lanka. This chapter outlines a prospective model for efficient disaster response operations in Sri Lanka by looking at the evolution of command and control structure, also considering the advantages derived by various communication mechanisms, information management systems and management of resources and first-responder coordination, chronologically.

The military parties currenlty leading the emergency situations are well versed about the result-oriented command system. Therefore, to meld rapidly into a common management structure, the inter-relationship between the components is clarified concerning the needs for joint planning, management and evaluation of Civil and Military agencies through the proposed CIMM-Modality. When creating command and control in relief operations, a shared doctrine is to be created in the response mechanism starting from C4-SAR. For the effective response, including efficient SAR missions, Command, Control, Communication and Coordination (C4) must be organized as a joint-operation system to perform various roles and tasks (of disaster response) with relevant stakeholders by integrating all standard operting procedures.

A multidisciplinary group consisting of stakeholder ministries, organizations and sub-national administrations responsible for responding to disasters are to be assembled as Incident Management Team (IMAT), to assist the incident commander of the CIMM implementation. Presently the main stakeholders in any incident response are the administrators of the various government departments at the National, Provincial, District and Divisional levels. Starting from "victims", as first responders, the roles of INGOs, NGOs, CBOs, PPPs, Volunteers and communities also need to be carefully integrated into the response mechanism.

Based on the different generation levels namely, Legislation-Level (DM Act), Policy/Strategy-Level (National Policy on DM); Plan-Level (NDMP, NEOP) and Operation-Level (ICS, CIMM), need to provide their support to legalize the guideline, as the standard response operational tool. Regulations for emergencies must be established as straightforward as possible and responsibilities for specific tasks in CIMM should be assigned to designated pool of individuals, in the relevant stakeholder organizations.

Policy decisions need to be taken to establish an appropriate Response Management tool (CIMM). Accordingly, the dedicated CIMM resource team must prepare course materials to conduct awareness and training and refresher courses for all stakeholders through a designated institute. A pool of National Trainers need to be utilized in pre-planning with necessary adaptations. All district administrative staff who are already familar with the election management system, should be trained on the command and control functions additionally. Exercises on encompassing full cycle of the crisis, are to be planned with a more dynamic and flexible nature with frequent drills and table-top exercises, to further test the different aspects of command and control.

The suggested modality allows parties from a variety of civil and military agencies to meld rapidly into a common management structure, by providing logistical and administrative support to the operational staff. Inter-relationship between the components show the needs for joint planning, management, evaluation, and evolution through the Coordinated Incident Management Modality (CIMM). Continuous coordination arrangements are needed up to tail-responses, where both civilian and military authorities help in smooth transfer and demobilisation of the same resources to complete the response cycle. Strong Civil-Military cooperation is to be further strengthened through CIMM for humanitarian tasks.

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The Downstream Mechanism of Coastal Multi-Hazard Early Warning Systems

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Abstract With the rapid increase of coastal hazards, many scientists have commended on the significance of effective coastal hazard early warning systems worldwide. An early warning system comprises four elements: detection and monitoring, risk analysis, warning dissemination, and preparedness and response mechanisms with three phases: upstream, interface and downstream. However, most existing early warning systems have not received equal treatment to all elements limiting its effective use of early warning in many instances. Hence, the study conducted a systematic literature review to examine the nature of the existing coastal hazard early warning systems and their current practices, identifying any gaps within the systems. The results revealed that most existing early warning systems are operated in isolation leaving most dimensions of the early warning systems disintegrated. Further, the minimum availability of guidance specifically on downstream mechanism was identified as a significant gap within the existing coastal hazards early warning systems. Therefore, the study proposes a conceptual framework as guidance on nature and the operationalisation of the downstream mechanism of coastal multi-hazard early warning systems, based on the desk review and followed by an expert consultative process conducted as a sandpit exercise. The study findings could be further developed based on primary data sources from coastal regions.

1 Introduction

The number of coastal disasters has increased over the years and is expected to increase drastically in the future within the climate change context (Spalding et al., 2014). While addressing the root causes of climate change and reducing disaster risk remain a major issue for discussion (Setyono & Yuniartanti, 2016).

A significant feature of natural hazards is their intersectional relationship of the geophysical events with the vulnerable communities. The impact of the hazard not

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only cause the loss of a large number of lives but continues to have natural and social consequences over an extended period (Kusenbach et al., 2010). It is essential to minimise the loss of lives and damage the economic and natural environment caused by natural disasters (Thomalla & Larsen, 2010).

Effective disaster planning, preparation and dissemination of early warning information has led to minimal death tolls and saved lives across the globe in the wake of the most devastating natural disasters (Harriman, 2014). In the Sendai Framework for Disaster Risk Reduction, the need for early warning systems (EWSs) was highlighted as the main target to be achieved by 2030 (Alfieri et al., 2012; UNISDR, 2015). Another global framework, the Sustainable Development Goals, further emphasises the necessity of global partnerships to support those who do not have capacities (United Nations, 2015). EWSs are essential requirements for all primary measures to be taken in the face of a disaster (Cumiskey et al., 2018). Because recovery operations usually benefit people those with power or influence, specifically in developing countries. Nevertheless, the warning systems benefit everyone in terms of saving lives. Thus, even the most impoverished countries have invested mainly in well operational EWSs and have succeeded in the face of natural disasters (Rogers & Tsirkunov, 2011).

However, there are some unfulfilled gaps in coastal hazard early warning systems. Therefore, this paper presents the findings of a systematic literature review conducted to explore the nature of the coastal-hazard early warning systems, primarily focusing on the downstream, which is the stage at which the national level warning is received, the impact is evaluated and, if needed, warning and evacuation orders are issued (Haigh et al., 2020). Section 2 provides a brief introduction to different phases of a multi-hazard early warning system. Section 3 presents the syntheses of coastal-hazards and coastal-hazard early warning systems and follows Sect. 4 presents the study methodology adopted to achieve its objectives. Section 5 presents the conceptual framework for the study and follows by the conceptual framework's operationalisation in Sect. 6. The conclusions of the study are presented in Sect. 7.

2 Phases of Multi-Hazard Early Warning Systems: Upstream, Interface and Downstream

Early warning systems have four main components: detection and monitoring, risk analysis, warning dissemination, and preparedness and response (Mukhtar, 2018; WMO, 2018). While reactive measures are common in most countries facing disasters, it is necessary to develop preparedness and proactive measures for effective risk reduction and resilience (WMO, 2017).

There is a need for the EWSs to operate beyond national borders to have an integrated and a common approach to face the disasters that affect many countries simultaneously (Alfieri et al., 2012; Hemachandra et al., 2019). The gaps in the warnings and warning systems can be filled by an integrated approach understanding the forecasting and warnings and combining the knowledge across disciplinary boundaries to develop end-to-end EWSs (Bostrom et al., 2018). Many scientists agree that EWSs should be an end-to-end process, and each component should be interconnected. This end-to-end process should also be people-centred, with the ultimate aim of building resilience among communities at risk (Jubach & Tokar, 2016; Mukhtar, 2018).

An end-to-end, EWS typically entails two main components of upstream and downstream mechanisms. In addition, there is an interface process (Sakalasuriya et al., 2018).

The upstream process is where the occurrence of the hazard is detected, and its impact is predicted. This process involves more technical aspects and the specialist scientific knowledge of the experts (IOC/UNESCO, 2015). After confirming the certainty of the hazard occurrence, the disaster management agencies decide to warn the communities. Accordingly, they issue the official warnings and guidance to take precautionary actions and facilitate the evacuation and safety provision.

Within the interface process, the decision to warn and evacuate communities is taken by the relevant authorities (Sakalasuriya et al., 2018). Comes et al. (2015) claim this to be between preparedness and response stage, which involves warning and evacuation decisions, deploying disaster relief teams and pre-position for logistics for relief. A significant level of differences can be identified among countries during this interface stage. The difference is mainly due to different administrative systems operated within countries. (Sakalasuriya et al., 2018).

The latter mechanism is known as the downstream (Bernard & Titov, 2015). Downstream is in nature multi-dimensional, as it includes institutional, legal, social and cultural aspects in addition to technology (Mukhtar, 2018; Sakalasuriya et al., 2018). It also necessitates using the knowledge from several disciples to provide successful solutions for EWSs. For the purpose of this paper, the process that takes place after receiving national warnings, the disaster impact is evaluated and confirmed, and, if necessary, warning and evacuation orders are issued considered as the downstream process. Figure 1 illustrates the three phases of the multi-hazard early warning systems.

3 Coastal Hazards and Coastal Hazard Early Warning Systems

One of the areas in which the EWSs are widely used is coastal hazards. Since the initial occurrence of natural phenomena occurs in the sea, there is more room for prediction for coastal hazards, and it also allows a certain amount of lead time to act accordingly. Climate change has also contributed to the rise of coastal hazards in coastal cities (IPCC, 2014). With the expected rise of coastal communities in coastal regions, the level of future coastal hazards is expected to increase further (Seto et al, 2011; Spalding et al., 2014).

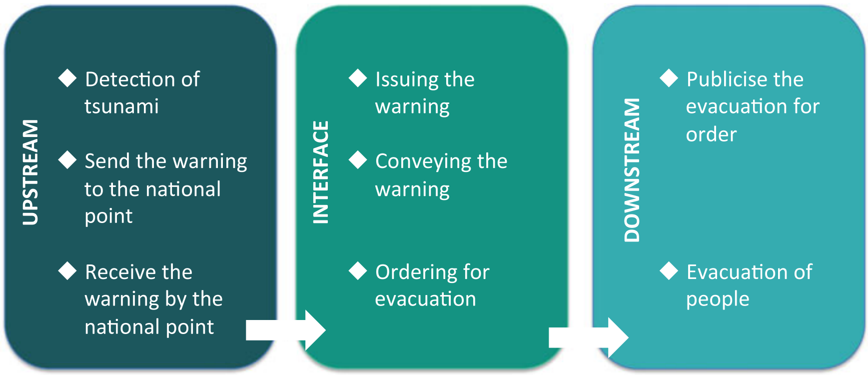

Fig. 1 Different phases of the multi-hazard early warning systems adopted from (Haigh et al., 2020)

Many scientists have identified the rising pattern of coastal hazards by the mid of the twenty-first century (Merkens, et al, 2016). The increased incidences of coastal disasters followed by the increased number of deaths have led the scientist and policymakers to improve the EWSs (Harley et al., 2016; Setyono & Yuniartanti, 2016).

Coastal hazard warnings are primarily focused on hydrodynamic forecasts for low-lying areas, and its effective operation can reduce the loss of lives in case of extreme events (Harley et al., 2016). While separate systems of detection and technical warnings are useful for different hazards, it is argued that the risk reduction plans, including warning and evacuation, should be compatible with coastal multi-hazards. Such EW systems could minimize the duplication efforts and risk substitution and maximise the operational and human capacities (Mahendra et al., 2011).

Since the highest number of coastal hazards were reported in Asia during the last few decades (Dutta & Basnayake, 2018), many countries in Asia focus on developing and improving current practices of coastal hazard EWSs for the region (Hemachandra et al., 2019). Sorensen (2000) advocates using different EWSs for different disasters due to the need for specialisation. Sharma et al. (2020) define cyclone EWS as a policy intervention to generate and communicate disaster information to the public. As a result, the communities can respond rapidly with appropriate actions to ensure their safety.

However, most existing coastal hazard early warning systems suffer from several weaknesses (Hemachandra et al., 2019; Lumbroso et al., 2016). For example, cyclone early warning is generally a linear communication process between recipient and issuing organizations (Sorensen, 2007). However, the effectiveness of cyclone early warning depends on various other factors: appropriate hazard detection, information dissemination, and people's responses. Most of such elements have been neglected (Paul, 2014). Similarly, the hurricane information system, complex in nature due to multiple channels and perspectives, is too complex to be understood.

Thus, the authorities tend not to issue direct warnings leaving the public unaware of the danger (Gladwin et al., 2007).

Thus, several scientists and policymakers have proposed introducing a multi-hazard approach to existing EWSs in several international events (Golnaraghi, 2012). The term multi-hazard early warnings were introduced in 1994 for the first time, and it was evolved over the period. Since then, on many occasions, the term Mult Hazard Early Warning (MHEW) was used to highlight its significance. Nevertheless, a clear and widely accepted definition had not emerged until 2017, when the First MHEW Conference was held in Mexico, Cancun. At the conference, the checklist for effective MHEW system was introduced with four interrelated elements: risk knowledge, detection, monitoring and analysis, warning dissemination and analysis and preparedness and response capacities (WMO, 2018).

However, the use of MHEW is not operated in many countries due to several reasons. One of the reasons was the lack of a common understanding of the terminology. As a result, several researchers attempted to understand the common terminology used in different countries when using MHEW systems. A team of researchers conducted a sandpit activity as part of the European Commission-funded project, Capacity Building in Asia for Resilience Education (CABARET), to understand the MHEW systems operated in four Asian countries identifying their national MHEW systems. Their findings revealed that the selected sample of four countries representing, Maldives, Myanmar, the Philippines and Sri Lanka adopted MHEW systems to a certain extent in their national disaster management strategies. The study also identified some gaps in each element of the MHEW systems at national levels. A key finding across the four countries was that the downstream phase has not been developed to the expected level showing many gaps in the downstream phase (Aguirre-Ayerbe et al., 2020).

In addition, several scholars have further highlighted many issues within the downstream phase of the EWSs. For example, communication of early warnings did not reach the most vulnerable communities (Adger et al., 2005; UN-ESCAP, 2015a, 2015b), issues related to receiving of early warning messages and lack of real-time data and equipment (IOC, 2015).

The downstream phase engages a variety of stakeholders at different levels to act proactively within a short period. The social and cultural aspects also become necessary elements of downstream as it is a people-centred mechanism. Irrespective of the complexity and dynamic nature, the authorities should ensure the effective operationalisation of the downstream process to assure resilience among communities. Therefore, the l chapter's later section provides an operationalized framework to strengthen the coastal multi-hazard early warning system. The following section presents the study methodology used to arrive at this objective.

4 Methodology

In this chapter, a detailed review of the literature was undertaken to examine the nature of coastal hazard early warning systems and the related impact on communities to understand the current state of the art practices and existing research gaps. In doing so, the scoping method suggested by Arksey and O'Malley (2005) was used by the authors. Accordingly, literature was selected, scoped and analysed systematically to achieve the specified outcomes.

Further to the literature review, a sandpit exercise was conducted to improve the robustness of the study findings. This sandpit exercise was conducted as part of CABARET, which aimed to understand the common features of coastal MHEW and thereby identify the key terminology used in MHEW. The sandpit activity was conducted and nourished with the experiences of experts representing 15 higher education institutions from Asia and Europe. This exercise provided key insights to develop further the conceptual framework identifying the key elements and their strengths and weaknesses within their national systems. Figure 2 presents the conceptual framework developed based on the literature review, which guided the sandpit activity.

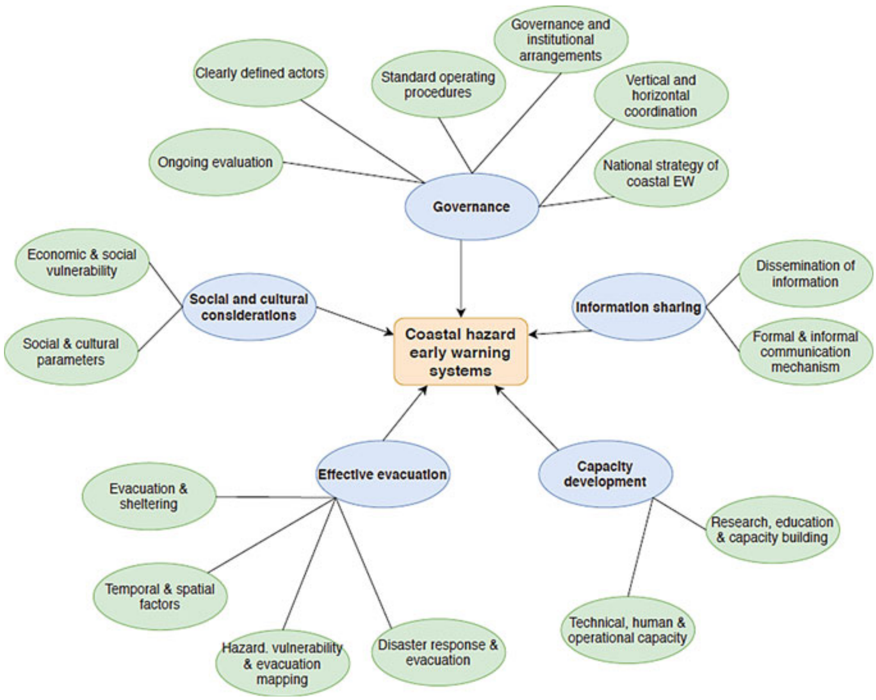

Fig. 2 The conceptual framework for coastal multi-hazard early warning systems

5 Conceptual Framework

A conceptual framework can be explained as a graphical or narration of the main items or concepts or variables or factors or constructs to be studied within a study (Grant & Osanloo, 2014; Miles et al., 2014). According to Sharon and Matthew (2016), a conceptual framework is adopted as a visual presentation of the study's structure or as similar to a theoretical framework or to connect elements of a research process. They consider a conceptual framework as a sequenced and logical proposition, which helps to support the study. According to Miles et al. (2014), a conceptual framework evolves with the study progression.

Accordingly, a conceptual framework provides benefits in many ways. According to Miles et al. (2014), it helps to present relationships between variables, factors or constructs and identifying the most significant and relevant areas to be studied in a study to achieve research objectives. Adom et al. (2016) explain that it improves research findings more meaningfully, acceptability and, more importantly generalizability. They further emphasise that a conceptual framework prevents any misunderstanding of the study's academic position and relevant hypothesis among readers. According to Imenda (2014), the researcher has the freedom to synthesise available concepts based on theoretical and empirical studies using a conceptual framework.

Having understood the benefits of using a conceptual framework in a study, the present study used a conceptual framework developed based on available literature and presented in Fig. 2.

6 Operationalisation of the Conceptual Framework of the Downstream of the Coastal Multi-Hazard Early Warning Systems

6.1 National Strategy of Coastal Early Warning

Scientists believe that there should be a national strategy for coastal hazard early warnings. Accordingly, the governments should introduce EWSs an essential component of their disaster management plans at all levels, from national to the community (Karanth et al., 2014). Most countries have a central national organisation to deal with information processing and developing warning messages (Jubach & Tokar, 2016). Each country must have an established practise of warning and evacuation practice when forming the national hazard warning strategy (Sorensen, 2000). The plans and policies should be in place to provide information and resources for communities to be safe from a disaster (Jubach & Tokar, 2016). For example, Sri Lankan national strategy for issuing early warning assigns the Disaster Management Centre (DMC) as the authoritative institution to issue any possible hazard warning to district, divisional and village level authorities. However, there is no specific national strategy for coastal-hazard early warning systems in Sri Lanka (Jayasiri et al., 2018).

6.2 Governance and Institutional Arrangements

The national disaster management strategy can be enhanced by incorporating effective governance and institutional arrangements, such as robust legal and regulatory arrangements, long term political commitment, local decision-making and participation, administrative and resource capacities as well as through vertical and horizontal communication channels between various stakeholders (Mukhtar, 2018). Legal authority and institutional arrangements are also central in forming effective partnerships between the national disaster management centre and other organisations (Jubach & Tokar, 2016) while governance and institutional arrangements are key to effective EWSs (Rogers et al., 2020).

Due to the non-existence of laws and regulations specific to disaster management, the organisations and decisions makers often do not have enough authority to prioritise warning and evacuation operations (Lumbroso, 2018). Alfieri et al. (2012) explain how the legal frameworks are effectively used in disaster planning and management in the European Union (EU). However, the laws and regulations are enormously diverse among the member countries, the every-day use of the legal framework for disaster response activities to ensure the safety of people. On the other hand, the EU regulations necessitate the countries to develop an effective management plan and institutional capacity to face natural hazards, particularly those exposed to frequent coastal-hazards. Jubach and Tokar (2016) point out that the governments must have a quantitative understanding of the warnings' social and economic costs and benefits and have clear guidelines to face the calculated risks. The governments should be able to fund the EWSs to provide the necessary facilitation and adequate warnings. In Sub-Saharan Africa, the inadequacy of government budgetary provisions for EWSs is a barrier to successful implementation. Due to lack of funding, the technological equipment is either out-dated or not maintained, making them unreliable for predictions (Lumbroso, 2018).

The World Meteorological Organization (WMO) regards political recognition as a key ingredient for effective EWSs. Political recognition benefits developing and implementing EWS at the local and national level (Harriman, 2014). Underfunding may lead to lack of authenticity about the warning agencies among the public. The public willingness to accept risk is strongly influenced by the level of trust the public has in risk managers and risk communicators (Kuppuswamy, 2014). Disaster management authorities must deliver reliable information to maintain public trust in governance.

Decision making is an important aspect in EWSs and the related outcomes. Similarly, governance with leadership, legal frameworks and established institutions enhance the resilience capacities (Rogers et al., 2020). The warning and evacuation decisions are taken known as 'meta decisions" due to their association with the authority of governance and timely deliberation (Platt, 2015). The traditional methods of decision-making focusing on individual safety cannot be applied for disaster decision-making. The involvement of households, families and social and private organisations, and national and international governance institutions requires understanding multiple dimensions of decision-making in disasters (Gladwin et al., 2007). The decision-making hierarchy from the national to the local level, is an important element in coastal hazards, as each proceeding level guides the activities and operation at the next level (Pal et al., 2017).

6.3 Standard Operating Procedures

When dealing with coastal multi-hazards, it is essential to introduce standard operating procedures. Different hazards encounter different risk identification and stakeholders engagement in risk communication etc. (Fathani, et al, 2016; Rasquinho et al., 2012). Thus, it is essential to introduce standard operating procedures (SOPs) among agencies that deal with MHEW. The use of SOPs has many benefits, such as easy to understand and easy to interpret for decision-makers including forecasters and dwellers.

The decision to evacuate has many consequences, such as impact on people, organisational and economic consequences. Therefore, it is essential to plan and evacuate according to a clear set of SOPs (Hissel et al., 2014). Having an established set of SOPs, the consequent operations can be effectively planned to face the disaster, including forming response teams, resource mapping, safety drills, public awareness campaigns, construction of shelters and stocking of provisions (Pal et al., 2017).

Thus, scientists suggest that robust SOPs are a vital for officers who issue warnings and the media to protect the lives at risk. Any misunderstandings could lead to a devastating impact on their lives (Rasquinho et al., 2012). SOPs are also considered as a guide for the disaster preparedness teams and the community when facing all hazard levels (Fathani et al., 2016).

Thus, SOPs should be regularly and comprehensively reviewed to overcome any possible challenges. Further, the SOPs should be evaluated for their realistic nature in terms of human and financial resources. Besides, good communication should be developed between the two parties involved. The media can be well informed when disseminating warning to enhance reliability and avoiding unnecessary panic among communities. Furthermore, National Disaster Management Offices (NDMOs) and local communities should have SOPs for different hazards (Rasquinho et al., 2012). Further, response procedures should be communicated with a specific alert. Fathani et al. (2016) also suggested discussing the SOPs developed with the local authorities and other relevant stakeholders.

6.4 Clearly Defined Actors and Their Roles

Researchers often emphasise the significance of establishing clearly defined roles and responsibilities of actors involved in disaster warning and response (Jubach & Tokar, 2016). Because, participation of multi-stakeholders is related to risk governance (Renn, 2015). Typically, several actors are officially recognised as crucial for coastal EWSs. However, a thorough examination of EWSs several actors, political and administrative officers are not recognised as a part of the system (Basher, 2006). There are organisations, individuals and communities that act proactively and significantly in the risk reduction process (Islam et al., 2004). Understanding all the actors' roles in decision-making and communication processes and providing recognition can contribute to improving the hazard EWSs to a greater extent (Bostrom et al., 2018).

WMO highlights that identifying the roles, responsibilities and coordination mechanisms of stakeholders from national to community level as a principle of DRR and that these specifications should be mentioned in all national to local level documents (WMO, 2017). In the European flood alert system, specified by EU commissions, all stakeholders's roles and responsibilities are set and considered critical guidelines in providing coastal hazard safety to member countries (Alfieri et al., 2012). In most countries, roles and tasks depend on demographic, geographic and political factors, and are changed over time according to local needs (InterWorks, 1998). The warning and evacuation units can be under single units or different units based on administrative structures and divided across several organisations at national and local levels. However, the emergency management units must perform the four essential functions of emergency assessment, expedient hazard mitigation, population protection, and incident management in a disaster (Islam et al., 2004).

6.5 Vertical and Horizontal Coordination

The roles and functions of the actors within the EWS are interlinked with each other, and no one cannot operate on their own. Therefore, healthy relationships among stakeholders can support the system's effective functioning (Pal et al., 2017). The close coordination of all actors related to disaster management at the national and local levels is an essential part of preparedness (Jubach & Tokar, 2016). The formal linkages should be established between relevant ministries and departments, especially between the federal and provincial government institutions. Furthermore, the coordination should be thoroughly managed and clarified within the departments at the same level before and after disasters (Mukhtar, 2018). It is essential to have comprehensive policies to specify the chain of command from the national to the local level, as the lack of such administrative structures can cause mismanagement (Pal et al., 2017). In some countries, the authority to issue warnings is decentralised across several agencies, creating confusion and failure instances. Due to fragmentation of systems and lack of consistency, both organisations and communities' responses tend to be uncoordinated and lack accountability (Lumbroso, 2018).

The coastal flood management system in the European commission provides a successful example of coordination among different institutions and at different levels, where information is often displayed on the web and freely accessible to public and private users (Alfieri et al., 2012). In most countries, the proactive response mechanisms fade out when it comes to the local and community level due to a lack of coordination from national policy to local communities (Lumbroso, 2018). After facing several difficulties in flood management in the UK, it was decided by Federal Forecasting Agency (FFC) to work together to deliver warnings and information on flooding (Stephens & Cloke, 2014). During, Cyclone Phailin in India, the corporation and effective communication between national and local officials have contributed to the successful preparedness and minimised damage to communities (Harriman, 2014). It is vital to establish effective relationships among the administrative and disaster management authorities and technical agencies as their role as warning formulators is highly significant. The disaster management agencies should coordinate and communicate effectively with the technical authorities at the institutional level (Karanth et al., 2014).

6.6 Dissemination of Information

Another important element to be considered when developing a MHEW system is the effective dissemination of risk information because it determines the sustainability of an effective EWS (Basher, 2006; Thomalla & Larsen, 2010). Examples of risk information are hydro-meteorological data, climatological data, demographic data to support their disaster preparedness measures and the development of risk maps (WMO, 2018). The daily briefing, bulletins, special reports, websites and workstations are used to formulate and disseminate risk data. Such databases are expensive and complex. Thus sharing risk information within the regions or countries could deliver a cost-effective early warning system (UN-ESCAP, 2015a, 2015b). For example, the Indian Ocean Tsunami Early Warning System (IOTWMS) shares risk information and coordinates early warning to its member countries (Basher, 2006).

6.7 Formal and Informal Communication

Researchers in disaster preparedness emphasise the need to deliver clear, consistent, specific and timely warning information through effective communication (Dash & Gladwin, 2007; Jubach & Tokar, 2016). Similarly, vertical and horizontal communication plays a significant role in the downstream process (Thomalla & Larsen, 2010). The timely and reliable information is the essence of EWSs, enabling organisations and individuals to act towards DRR (Comes et al., 2015). Communication should not be a linear one-way process, but rather should work on every direction linking all the networks back and forth (Mukhtar, 2018). The authorities should share the information on the severity of disaster and expected outcomes, and the uncertainty of the calculated predictions (Jubach & Tokar, 2016). Disaster preparedness of communities directly influenced by the frequency and the reliability of the information and the strategies used for communication and feedback (Kuppuswamy, 2014).

A risk communication protocol as a guideline in communicating risk to downstream has been identified as an effective strategy (Yang, et al, 2004). The use of well-established prototypes for warning and evacuation messages can improve the clarity and understanding of warning information (Sorensen, 2000). Most countries adopt systems of colour coding, numbered bulletins or levels of warning alerts to facilitate the dissemination and communication of warning information both to authorities and to the public. When communities become familiar with such communication's standard practice, the messages become easy to interpret and understand, ultimately improving the proactive responsiveness (Cumiskey et al., 2018). For example, the numbered signal system was practised in Hong Kong for cyclone warnings over a more extended period making it familiar to the public. Coupled with well-coordinated relief operations, Hong Kong cyclone EWS has proved to be a successful implementation (Rogers & Tsirkunov, 2011).

Warning technologies have been improved over time. While sirens are most commonly used, loudspeaker announcements, electronic and social media are also increasingly used in many countries (Sorensen, 2000). The use of different platforms for communication has resulted in different outcomes among the communities. The usage of media should be decided depending on availability and accessibility. Usage of advanced technologies and web-based data storage methods help experts' decision -making at the organisational levels (Sabino et al., 2018).

The warning and evacuation messages should be accessible, clear and easy to understand (Kuppuswamy, 2014). Poor communication of warning to the public has resulted in communities' inadequate response limiting available time for actions (Lumbroso, 2018). Islam et al. (2004) explain how access to broadcast media had a positive relationship with the family's income level and reveals that the poverty-stricken people living near the coast often do not have access to such facilities. They also show economic factors, age, location and several other social factors can contribute to access and interpretation of warning messages delivered by the authorities.

It is necessary to use various communication methods to reach a diverse population (Gladwin et al., 2007). The use of mobile and social media is increasingly used in warning communication in all countries, both at the institutional and community levels (Harriman, 2014; Paul & Dutt, 2010; Roy et al., 2015). It is necessary that people exposed to coastal hazards, and particularly those who live near the sea line, should have access to day-to-day weather forecasts and information in an easily understood manner, and make the weather forecasts and warning information available through multiple channels for fishers and those who use the sea for livelihood.

6.8 Technical, Human and Operational Capacity

The technical processes and human capacity used in the formulation and dissemination of warning messages tend to decide the accomplishment of effective EWSs (Roy et al., 2015; WMO, 2018). From the national to communal level, the technology is used in detecting the hazards, dissemination, communication and evacuation processes. It is essential to maintain and evaluate the technical capacities and develop the capacities over time as required (Karanth et al., 2014). The EWSs cannot afford to fail during the emergency since there is a massive liability of delivering authentic information. Therefore, maintaining and updating all the system's technologies is always a priority (Bernard & Titov, 2015). Countries' technological capacities tend to develop over time depending on scientific knowledge advancement and increased exposure to disasters. The situation was the case in some Asian countries exposed to frequent disasters (Grabowski & Roberts, 2011). Due to unreliable warning systems and resulting mistrust in certain parts of Bangladesh, there is a tendency for communities not to follow the the national warning authorities' instructions (Roy et al., 2015).

Capacity building through skilled and trained professionals is an essential part of disaster preparedness. According to Pal et al. (2017), well-trained personals must be employed in disaster mitigation, monitoring and management activities. Formal knowledge of risk management and an understanding of social and psychological aspects contribute to effective risk management. It is essential to use highly experienced experts to deal with technical aspects of detection and forecasting and policy formulation, and decision-making. In his study, Lumbroso (2018) provides examples of how the lack of human capacity at the national level, warning formation and decision-making significantly impacted the communities' response. The employees in the disaster warning and management sectors can be given formal and, on the job, mandatory training, combining the scientific knowledge of warning formulation with management skills of disaster management and decision-making (Stephens & Cloke, 2014). Concerning coastal disaster management, it is essential to train all stakeholders on emergency management and safety measures to be followed before, during and after the disaster (Alfieri et al., 2012).

6.9 Temporal and Spatial Factors

The disaster management operations vary significantly depending on the circumstances, and when planning needs of the end-user or the community, the different temporal and spatial scales should be taken in to account (Jubach & Tokar, 2016). Temporal dimensions of a disaster warning and evacuation operation include timely decisions, preparation, evacuation within delay to disaster or lead time, and post evacuation management (Hissel et al., 2014). The time leading to disaster is a crucial element in warning and evacuation operations (Comes et al., 2015; Jubach & Tokar, 2016). The supporting evidence on which the warning decisions are based can be increased over time, resulting in an accurate decision (Roy et al., 2015). Availability of resources and adequate lead time can positively impact forecasting and warning capabilities (Cumiskey et al., 2018). Six days of lead time before cyclone Sidr in Bangladesh allowed authorities to implement a well-planned and thoroughly rehearsed warning and evacuation mechanism, resulting in low death rates (Rogers & Tsirkunov, 2011). The information about the hazard also become more accurate as the time passes, allowing more proactive responses (Comes et al., 2015).

6.10 Hazard, Vulnerability and Evacuation Mapping

Vulnerability mapping is an essential part of coastal hazard EWSs, and they convey precise details of the magnitude, frequency and area of effect for a disaster. According to Mahendra et al. (2011), multi-hazard maps are less used in Indian ocean region, and there is a possibility to incorporate them into current planning as an effective tool to create awareness about coastal hazards. While it is common to have different hazard maps for different types of disasters, multi-hazard maps can be composed by synthesising and overlaying the different hazard maps. Mahendra et al. (2011) suggest that multi-hazard vulnerability mapping can be integrated into risk reduction planning and policy to easily understand multiple coastal hazards.

Hazard and vulnerability mapping and evacuation map can be introduced. The evacuation map provides information about the zones of both safe and unsafe and safe evacuation routes and safe evacuation places (Fathani et al., 2016). These maps are developed by the disaster preparedness and response teams with the support of the local communities as part of preparedness and response efforts (Karnawati et al., 2013).

6.11 Research, Information, Education and Capacity Building

For the successful operation of an EWS, the system's outcomes, the information that the system is relying on to operate and the risk reduction aspects should be clearly defined (Jubach & Tokar, 2016; Roy et al., 2015). Haigh et al. (2018) stress the importance of knowledge transfer and capacity building to improve the multi-hazard EWSs. Public education about the nature of disasters and the necessary precautionary actions is a continuous process that should be practised by the disaster exposed communities. It is essential to conduct a pre-emergency information awareness programme for the public about each potential disaster and give them opportunities to get trained in evacuation practices (Sorensen, 2000). At the same time, organisations as well as communities should have easy access to information and resources to prepare for disasters in the future (Jubach & Tokar, 2016). Information can be used to link the preparedness with the response effectively and clearly outlined intervention points for actors at all level (Comes et al., 2015). The risk of the disaster should be perceived at the same level by both professionals and the non-specialist communities to gain a homogeneous and a collective response (Bostrom et al., 2018).

Public awareness and education are fundamental in the process leading to the collective understanding of risk, and the appropriate response (WMO, 2017) underline community training and awareness as one of the fundamental principles of good practices in EWSs. From the studies conducted in many countries, prior awareness and public education allowed people to act proactive and adopt necessary safety measures. Haque et al. (2012) claim that the number of fatalities and injured were reduced during the cyclones in Bangladesh due to increased awareness and communication. According to Bostrom et al. (2018) education is the primary method of preparing people for hurricanes, and information should be spread using multiple platforms of printed, electronic and social media. In Pakistan, the absence of awareness on risk information and lack of focus on education have been barriers to people's developing response capacity (Mukhtar, 2018).

6.12 Socio-Cultural Parameters and Community Participation

As the EWSs are essentially people-centred, there is a need for social science research on forecasting and warning disasters to facilitate people's safe evacuation (Phillips & Morrow, 2007). Social and cultural factors affect the evacuation decisions and safety of people during a disaster. It is necessary to accept the potential risk and develop trust in warning institutions, practise safe driving methods in the face of disaster and prioritise socially vulnerable individuals (Hissel et al., 2014). These practices could be developed by building a collective culture of disaster preparedness.

In addition to social and economic factors, culture can also affect vulnerability, such as dress code, religious beliefs, gender issues, rape and violence. Such socially constructed vulnerabilities should be addressed when planning for disaster risk reduction, especially in evacuation and sheltering (Howell, 2003). Specific communities tend to believe in the traditional warning and forecasting methods such as astrology, natural phenomena and animal behaviours. It helps find means of integrating such knowledge into EWSs, as they are easily understood, believed by local communities and transferable at a zero cost (Howell, 2003).

By incorporating local knowledge and community participation into EWSs, a sense of ownership, freedom, trust and autonomy is given to the communities. It also provides an opportunity to oppose unjust developments that do not benefit the communities at large (Santha et al., 2014). The communities react to emergencies not as isolated individuals but rather in the context of their interactions with other people or as a collective response (Roy et al., 2015). It is crucial to building communities' trust for the warning messages through strong collaboration between communities and disaster managers. The warning and evacuation practices should also be gender inclusive, culturally acceptable, sustainable and low-cost initiatives that can empower the communities to operate workable solutions in the face of unexpected failures (Mukhtar, 2018).

6.13 Ongoing Evaluation

The need for continuous and regular evaluation of the EWSs is often emphasised by the researchers (Lumbroso, 2018; Mukhtar, 2018). The effectiveness of warning response is measured by the SOPs, training and hazard drills. These measures must be updated regularly, and feedback is given after each measuring exercise to improve the system (Cumiskey et al., 2018). The sources of finance for EWSs should be uninterrupted, and the operation and maintenance should be continuously supervised under designated authorities within the governance system (Mukhtar, 2018). At the administrative and management level, the evaluation must also be undertaken at the community level regularly. Regular drills should be incorporated into community education and awareness programmes, and the results should be reported back to the relevant institutions to update the risk preparedness process and minimise shortcomings (WMO, 2017).

6.14 Economic and Social Vulnerability

Vulnerability plays a significant role in evacuation and needs to be considered during the evacuation planning before the disaster. It is essential to identify and understand the potential impact that social and economic vulnerabilities have on individuals and communities' evacuation (Hissel et al., 2014). WMO (2017) insists on preparing emergency response plans with consideration for risk levels and characteristics of the exposed communities. Vulnerability is the amount of exposure or the community's susceptibility to the damages caused by a hazard event (Comes et al., 2015).

According to Mahendra et al. (2011) vulnerability depends not only on proximity to hazards but also on social and economic factors. Past experiences of disasters, the extent of trust in authorities, the type of house, financial security and community networks are identified as critical determinants of disaster vulnerability (Cumiskey et al., 2018). Disaster vulnerability is a combined result of exposure to physical hazard and the socio, economic and political processes created by the community (Kusenbach et al., 2010). Due to disadvantageous economic situations and lack of accessibility, the rural communities are often more vulnerable to hazards than people in urban areas (Paul, 2014). In developed countries, while most people may use personal vehicles, there will be those relying on public transport even during a brief time leading to disaster. Such communities may include economically disadvantaged, people under care, homeless and tourists (Hissel et al., 2014). It is generally assumed that information passed through electronic and social media will be received by the wider community. However, there are economically vulnerable households and individuals who rely on loudspeakers, sirens or VHF based communications for warning information (Kuppuswamy, 2014).

Individuals' social vulnerability could result from structural factors such as socioeconomic status, ethnicity, and age. Social vulnerabilities may negatively impact their ability to prepare for and recover from disasters (Kusenbach et al., 2010). Socially vulnerable communities include people with special needs and restricted mobility (Hissel et al., 2014). Disaster managers at the local level must have collected demographic information about communities' vulnerabilities to facilitate the warning and evacuation process. Special attention should also be given to training and educating vulnerable community members such as sick, physically challenged, non-neurotypical people, babies, pregnant women, rather than assuming them to be included in awareness programmes targeted at the general public (Phillips & Morrow, 2007). The probabilistic risk approach is a method implemented in the UK to measure warning based on the risk of damage rather than the magnitude of the disaster (Dale et al., 2014; Stephens & Cloke, 2014). The critical assessment of vulnerability that focuses on all demographic, physical and economic aspects can contribute take successful early warning decisions (Comes et al., 2015).

6.15 Disaster Response and Evacuation

It is important to note that evacuation is not the only response to coastal disasters, while the most common response to tsunamis and hurricanes is evacuation. It is possible to stay at a sheltered place, including home, during specific coastal hazards, and mass evacuation is often considered the last resort option when other safety options are not adequate (Hissel et al., 2014).

However, it is necessary to adapt construction and housing to be physically resilient to hurricanes and have adequate supplies to stay indoors until the risk is completely depleted. Warning source is generally known to have a significant impact on evacuation behaviour. Mazer et al. (2015) claim that certain sources like direct information from the community or law enforcement officers are more trusted in certain situations than media. The type of resources that people rely on may also depend on the ethnic or social background of the community. According to Kuppuswamy (2014), people tend to exhibit information-seeking behaviours, particularly during natural disasters and make an effort to understand the threat before precautionary actions or evacuation fully. The evacuation decisions are also influenced by the reliability of the information, perceptions and knowledge of individuals, prior experiences, logistics after the evacuation, and social and environmental factors (Paul, 2014; Roy et al., 2015; Sharma et al., 2020).

Hissel et al. (2014) claim that evacuation in the face of a disaster is a complex and dynamic process that involves many elements and stakeholders to work together effectively to ensure the safety of the people. It is essential to include expert knowledge in evacuation planning and historical, geographic and demographic data. The communities and authorities should also prepare for unexpected failures and blockages that can evolve during the evacuation process, such as communication and transport blockages. Paul (2014) emphasises the need to locat temporary shelters within a workable distance. Thus, communities would be able to evacuate within the lead time. Some of the reasons for not being able to evacuate during coastal disasters include shelter characteristics, an insufficient number of shelters, the uncertainty attributed to the warning messages, inadequate transport facilities and the respondents' features, (Paul & Dutt, 2010; Roy et al., 2015) access to broadcast media, location of the house and the previous disaster experience, and the access to education have a significant impact on the disaster response in coastal hazard situations (Islam et al., 2004). It is essential to have a clear understanding of people's response behaviours and barriers to evacuation through continuous evaluation and work in collaboration with communities to overcome the barriers (Kusenbach et al., 2010).

6.16 Sheltering, Logistics and Security

The construction of shelters within reachable distance to the coastal belt, particularly for tsunamis and cyclones, have proved to be an effective method of saving lives over the recent years. However, finding appropriate shelters in overpopulated areas remains a challenge to several countries' disaster managers (Kuppuswamy, 2014). As mentioned before, these shelters should be easily accessible and accommodate a large number of people during the disaster situation and equipped with all the facilities to support them over the disaster period (Paul & Dutt, 2010). They must prepare in advance for their wellbeing by purchase adequate supplies of food and medicine in advance (Bostrom et al., 2018). To deliver an effective response, people tend to understand in the risk faced by them and their families in detail, such as safety for property, pets and livestock (Kuppuswamy, 2014). People adopt safety measures before evacuation, such as keeping the furniture inside, tie down the essential items to walls, and building moulds securing livestock (Bostrom et al., 2018).

7 Operational Framework of the Coastal Multi-Hazard Early Warning Systems (of the Downstream Mechanism)

The elements mentioned above were further explored and refined during the sandpit exercise among experts representing 15 higher education institutions from Asia and Europe. The sandpit exercise aimed to enhance coastal resilience through capacity building among higher education institutions towards strengthening multi-hazard early warnings in Asia. The final framework was developed based on the initial detail literature review and the consultative process conducted during the sandpit exercise. The sandpit exercises helped to identify and operationalize each variable or concepts under key thematic areas. Table 1 presents the final framework of the coastal multi-hazard early warning systems of the downstream phase.

8 Conclusions

Coastal hazards have become an increasing hazard within the climate change context, increasing population and rapid development initiatives. Many scientists and policy-makers have emphasised the importance of developing coastal hazards early-warning systems within their national and regional systems. People-centred and end-to-end multi-hazard early warning systems were strongly recommended for coastal hazards due to their multi-hazard nature. MHEW systems comprise of four interrelated elements with three different phases. Efforts have been placed to strengthen the exiting EWSs. However, EWSs does not deliver the intended outcomes due to the lack of clear guidance on the downstream phase.

Therefore, the study conducted a systematic literature review, and a sandpit exercise to validate the literature review findings and to operationalize the initial framework to strengthen the downstream of the coastal multi-hazard early warning systems. The operationalised framework needs to be further tested for further refinement based on a primary data collection from coastal regions. Accordingly, the final framework would support countries and regions to improve their coastal-multi hazard EWSs and thereby to enhance resilience among coastal communities.

Table 1 Operational framework of the downstream mechanism of the coastal multi-hazard early warning systems

Key concepts	Elements to be operationalized
1. Governance	
a. The national strategy of coastal early warning	• Divide national strategies for each disaster • Integrated national strategy for coastal disasters • Integrated national strategy for all disasters • Prioritising the coastal early-warning within other disasters and other issues of the country
b. Governance and institutional arrangements	• Rules and regulations • Legal frameworks • Political commitment • Establishment of decision-making structures • Financing the early warning systems • Establish public trust towards risk managers and communicators • Prioritising EWSs among other issues in the country • Perceptions of benefits and costs of EWSs • Multi-stakeholder participation
c. Standard Operating Procedures	• A comprehensive review of SOPs • Analyse SOPs in terms of human and financial resources • Develop a good communication system between the EW specialists and the early warning users • EWs should be communicated concisely in layman's terms • Well informed and educated media • National Disaster Management Offices (NDMO) and local communities need to have SOPs for taking action depending on hazard types
d. Clearly defined actors	• Multi-stakeholder participation • Clearly defined roles and responsibilities • The clear specification should be documented from national to local levels • Legal authority
e. Vertical and horizontal coordination	• Healthy relationships between: a. Among national actors b. Among national and local actors c. Among local actors • Monitoring of coordination within departments • Introduce comprehensive policies to avoid mismanagement • Public-private partnerships • Partnerships between stakeholders including technical agencies and communities • International partnerships

(continued)

Table 1 (continued)

Key concepts	Elements to be operationalized
f. Ongoing evaluation	• Continuous and regular evaluation of the EWSs • Amend after feedback evaluations • Continuous provision of finance for EWSs • Continuous operation and maintenance under supervision • Evaluation at the community level regularly • Testing of the EWSs • Training, drills and community awareness
2. Information sharing	
g. Dissemination of information	• Maintenance of risk information as databases • Use of reports, websites and workstation to process and disseminate risk data • Sharing of risk data among regions and countries
h. Formal and informal communication mechanisms	• Within and among warning and dissemination agencies • Communication to the public • Timely dissemination of warning • Communication should be linked with networks back and forth • Reliable warning to take immediate actions • Clarity and consistency • Public access/ownership of media used by the warning agencies • Communication of information on the severity of the disaster • Use of protocols for warning communication • Decide the use of different platforms based on the availability and accessibility • Use of a variety of communication methods • Use of clear signals and codes
3. Capacity development	
i. Technical, human and operational capacity	• Evaluation of technical capacities of the warning dissemination • Develop capacities over time • Maintaining and updating all the technologies in the system • Well-trained personals are employed in disaster mitigation, monitoring and management activities • Training all stakeholders at all levels on emergency management and safety measures
j. Research, education and capacity building	• Knowledge transfer and capacity building to improve the multi-hazard EWSs • Continuous public education about disasters (pre-emergency information awareness programme) • Continuous practice of precautionary actions • Easy access to information and resources by organisations and communities • Risk should be perceived similarly by both professionals and the non-specialist communities

(continued)

Table 1 (continued)

Key concepts	Elements to be operationalized
4. Effective evacuation	
k. Hazard, vulnerability and evaluation mapping	• Develop vulnerability maps • Convey of clear details of the magnitude, frequency and the area can be affected • Use of multi-hazard maps • Introduce multi-hazard vulnerability mapping into risk reduction planning and policymaking • Introduce evacuation maps • Identify zones of both safe and unsafe and safe evacuation routes and safe evacuation places in evacuation maps • Maps should be developed by the disaster preparedness and response teams with the support of the local communities
l. Temporal and spatial factors	• Consideration of different temporal and spatial scales • Availability of resources • Decides the adequate lead time for different hazards
m. Disaster response and evacuation	• Adapt construction and housing to be resilient • Deciding the appropriate warning sources • Evacuation decisions depend on the reliability of the information, perceptions and knowledge of individuals, prior experiences, logistics after the evacuation, and social and environmental factors • Collaboration and coordination of multi-stakeholders • Use of expert knowledge in evacuation planning • Prepare for unexpected failures and blockages that can evolve during the evacuation • A clear understanding of response behaviours of people and barriers to evacuation
n. Evacuation and sheltering	• Construction of shelters within reachable distant • The accommodation should be enough for a large number of people and equipped with all the facilities • People should adopt safety measures before evacuation
5. Social and cultural considerations	
o. Social and cultural parameters	• Engagement of social science researchers on forecasting and warning disasters • Building a collective culture of disaster preparedness • Consideration of socially constructed vulnerabilities when planning for DRR • Integration of local/indigenous knowledge • Build trust among communities for the warning messages through strong collaboration • Community participation
p. Economic and social vulnerability	• Consideration of hazard vulnerability • Consideration of social and economic vulnerability • Collected demographic information of communities • Training and educating the vulnerable community • Use of critical assessment of vulnerability

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A Conceptual Framework for Social Media Use During Disasters

Gaindu Saranga Jayathilaka, Chandana Siriwardana, Dilanthi Amaratunga, Richard Haigh, and Nuwan Dias

Abstract Social media is a prevalent and evolving communication channel that allows users to create contents, consume and share with a wider community. It is seen that there is a high potential to adapt social media in disaster risk reduction and management (DRR&M) as an advanced communication channel by facilitating communication and dissemination of disaster-related information to a wider community, based on the lessons learned from previous disasters that have been reported around the world. It has also been identified by researchers and practitioners as an essential communication channel that can supplement traditional channels because their application to disaster risk management provides the users with new benefits. The development of a conceptual framework for the use of social media in disasters was recognized as a key requirement for strengthening social media practices in DRR&M by addressing their prevailing gaps and barriers and it will be useful for future research studies on the use of social media in DRR&M. A comprehensive literature review was carried out in this study to develop this framework which has been formed on two major concerns in the context of using social media in a disaster: Uses and Users of social media in disasters. With the aid of the developed framework of this study future studies are expected to be carried out in the context

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of the implementation and development of best social media practices in disaster situations.

Keywords Social media · Disasters · Disaster risk management · Disaster risk communication

1 Introduction to the Disasters

A hazard is a process, phenomenon or human activity that can cause loss of life, injury or other impacts on health, damage to property, social and economic disturbance or deterioration of the environment ("UNDRR Terminology," 2017). With the degree of the human involvement, a hazard can be moved from natural to anthropogenic (as shown in Fig. 1) and with the high level of human involvement, hazards are become more voluntary in terms of their acceptance and more diffuse in terms of their disaster impact. (Smith & Petley, 2009). Hazards have become a global phenomenon of great concern, as they can transform into disasters that endanger human lives and properties (Shehara et al., 2019a, 2019b). Disaster is a significant disruption of the functioning of a community or society at any level due to hazardous events that interfere with exposure conditions, vulnerability and capability, resulting human, material, economic and environmental losses and impacts ("UNDRR Terminology," 2017). Over the recent past, various types of hazards have been occurring all over the world which turned into disasters and have made a severe impact on human lives, infrastructure, environment and economy. 2004 Ocean Tsunami, Haiti Earthquake in 2010, Tohoku Earthquake and Tsunami in 2011, Hurricane Sandy in 2012, Mexico

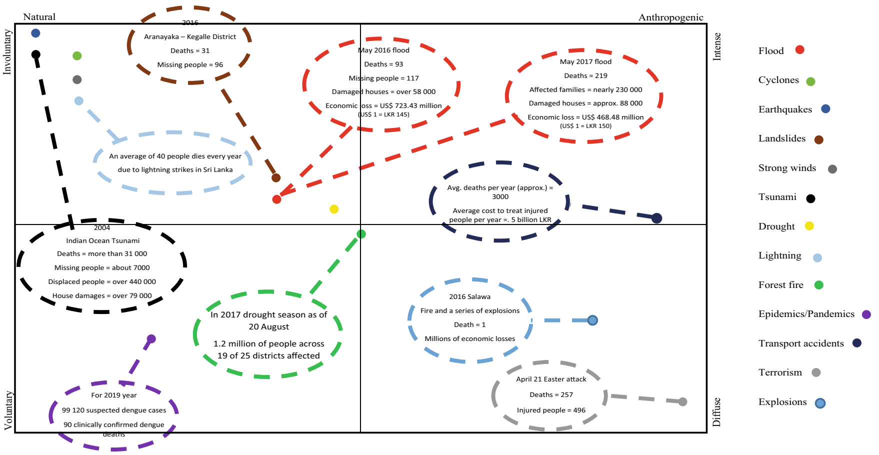

Fig. 1 Various types of hazards reported in Sri Lanka during the last 20 years and some of the disasters caused by them (It has been shown that the changing of characteristics of each hazard ac-cording to the extent to which human activities affect it)

Earthquake in 2017, Sierra Leone Floods and Landslides in 2017, Japan Floods and Mudslides in 2018 are some of the catastrophic disasters which were occurred around the world with less human involvement over the last 20-year period, causing severe damages in terms of the number of victims, the number of deaths and the economic loss (Kankanamge et al., 2019; "Natural Disasters 2019—World," 2019). September 11 terrorist attack, the Exxon Valdez oil spill, The Flint Water Crisis are the some of the disasters which have been reported over the world with higher intervention of people and a considerable damages and losses have been recorded due to these disasters (LaSane, 2019; Sawe, 2019).

Sri Lanka also has been experiencing various types of hazards which have turn into disasters over the past years ("Asian Disaster Preparedness Center & UNDRR," 2019). According to the Sri Lanka Disaster Management Act No. 13 of 2005, human lives, properties and environment are threatened and endangered because of certain hazards and their subsequent disasters occurring over the territory of Sri Lanka and it has listed twenty-one (21) types of hazards that are commonly reporting in Sri Lanka. ("Sri Lanka Disaster Management Act, No.13 of 2005," 2005). Sri Lanka was ranked as the second most affected country by climate change in the year 2017 ("Global Climate Risk Index 2019," 2019) and therefore, floods, cyclones, strong winds, landslides and droughts are the most frequently occurring natural hazards in Sri Lanka. Apart from that, lightning strikes, coastal erosion, fire incidents and various kind pollutions can be also seen in Sri Lanka (Amarasinghe, 2013). And also, vector-borne epidemics such as dengue fever have been also reported over the country during the past and recently it is being affected by the global pandemic of COVID-19. Tsunami has been categorized as an infrequent hazard in Sri Lanka and with the catastrophic devastation caused by the 2004 Indian Ocean tsunami, it was revealed that tsunami has the most crucial impact to the country which can be caused by a disaster (Arnold Margaret et al., 2006). At the same time, Sri Lanka has been undergone with several hazards induced entirely or predominantly by human activities and choices that have made a crucial impact on lives and properties. As an example, a garbage mound located at Kolonnawa was collapsed on 14th of April 2017 and a considerable damages and losses were reported due to that catastrophic event ("Meethotamulla," 2017). Figure 1 shows the various types of hazards and some of the disasters caused by them which reported in Sri Lanka during the last 20 years. Each hazard has been pointed out according to the changing of its characteristics based on the human intervention (Imtiyaz, 2020; Premalal and Kumarasinghe, n.d.; "Salawa-Wisalawa & Man-Made Disasters-Colombo Telegraph," 2016; "Sri Lanka: Dengue Outbreak," 2019; "UNDP Sri Lanka," 2016, 2017).

2 Disaster Risk Management

Disaster risk management involves a sum of all events, services and actions that can be taken before, during and after a disaster with the goal of preventing a disaster, and its impact or recovering from the loss (Khan et al., 2008). Three major phases of activities in disaster risk management can be identified as before a disaster (Pre-event), during a disaster (Event), after a disaster (post-event) and there are other three intermediate phases named as pre-event to event, event to post-event and post-event to pre-event (Herold & Sawada, 2012; Houston et al., 2015b; Khan et al., 2008; Le Cozannet et al., 2020). By considering these stages and the related actions of them, Disaster Risk Management Cycle has been developed which is a continuous process that goes through the phases of risk reduction, emergency response and recovery and it illustrates the activities which are proceeded by several parties such as general public, government and organizations to reduce the damages and losses of disasters (Harrison & Johnson, 2016; Khan et al., 2008; Poser et al., 2010).

2.1 Importance of the Disaster Risk Communication in Disaster Risk Management Cycle

Risk communication in the context of disasters is an essential component in Disaster Risk Management as it forms people's perception about the risk of the disaster and it affects to the intervention decisions and the actions that are made throughout the Disaster Risk Management Cycle (Shaw et al., 2013). The objective of the disaster risk communication is to disseminate information about the risk and consequences of a disaster and how the behavior can impact the outcome of the disaster (Reynolds & Seeger, 2005). Substantially increase the availability of and access to disaster risk information to people by 2030 is one of the seven global targets which has developed in Sendai Framework for Disaster Risk Reduction (SFDRR 2015–2030) to achieve its outcomes and goals ("Sendai Framework for Disaster Risk Reduction 2015–2030," 2015). Timely and accurate information is essential for the effectiveness of the actions taking during the response and recovery phases of a disaster incident (Morton & Levy, 2011). Figure 2 illustrates the importance of the Disaster Risk Communication with the activities in Disaster Risk Management Cycle.

3 Communication Channels

Risk communication can be taken place through various channels which are the ways that information disseminates between the sender and receiver (Bradley et al., 2014). Communication channels play a vital role in the Disaster Risk Management Cycle which can be used to help prevent a disaster or lessen its impact (Houston et al., 2015b; Takahashi et al., 2015). For instance, communication channels are critically involved for early warning action which is taken under the preparedness in the risk reduction stage of Disaster Risk Management Cycle. Communication channels can be divided into two: as traditional channels (old media) and modern channels (new media) (Danaher & Rossiter, 2011) and both of them have been using as a channel for

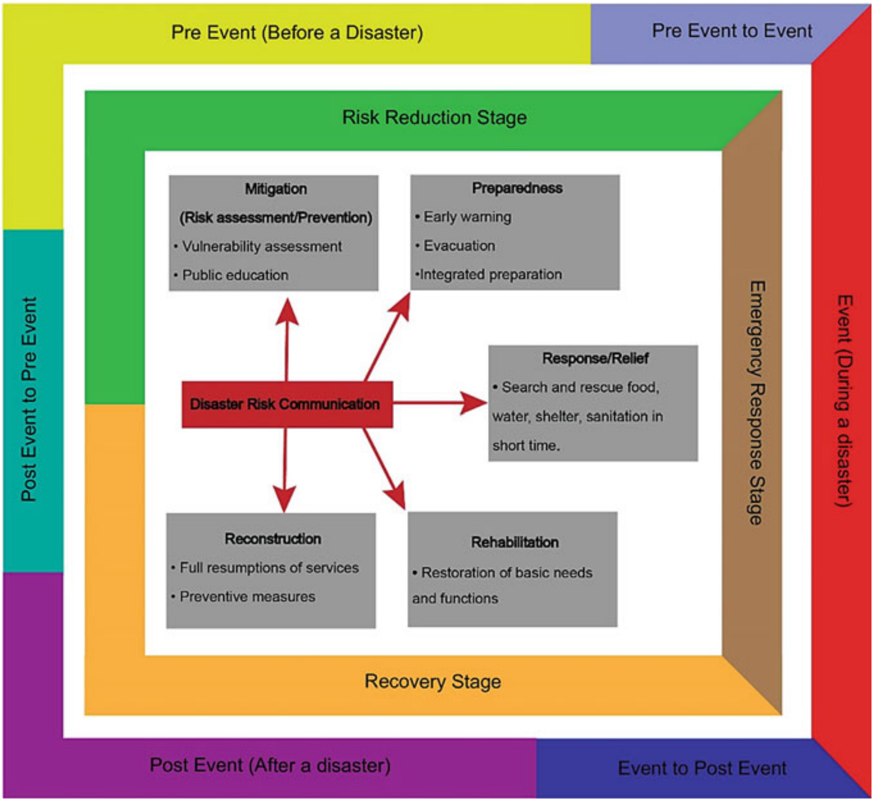

Fig. 2 Importance of the disaster risk communication in disaster risk management cycle

communicating disaster risk information by the general public and the other relevant stakeholders which are responsible in DRR&M (Feldman et al., 2016).

3.1 Traditional Channels

Traditional channels can be considered as any form of mass communication available before the advent of digital media (Johnson, 2015). Before the twenty first century, traditional media has been involved widely to distribute the information about the

Table 1 Different types of traditional media (Danaher & Rossiter, 2011; Feldman et al., 2016; Lindell & Perry, 2012; Tang et al., 2015)

Print	Newspapers, magazines, brochures, media advisories
Electronic	Radio, television
	Telephone
	Route alert (distributing warnings from moving vehicle)
	Tone alert, radio siren
	Internet (World Wide Web)
In person	Conversation between two people, group conversation or presentation

disasters (Tang et al., 2015). Table 1 presents the several types of traditional media which have been categorized according to the way of distributing information through that media.

3.2 *Modern Channels*

With the rapid development of the Information and Communication Technology, people have been tended to utilize modern channels which are internet and the mobile telecommunication-based communication channels as an alternative means of communication in disaster situations due to various reasons such as convenient, interactive and timely communication. Mobile applications, alert message services can be introduced as an example for the modern channels. As an advanced technical facility, nowadays, use of social media for disaster risk communication has become common practice among the public.

4 Social Media

4.1 *Global Context*

Social media is an extensive term for a variety of internet-based applications and services which operate under the principles of Web 2.0 (Houston et al., 2015b; Luna and Pennock, 2018). Social media facilitates to connect various parties or users together and share information broadly (Lindsay, 2012). With the rapid development of mobile technology social media has been evolved over the years and therefore individuals are better connected with the rest of the world than ever before (Tang et al., 2015). At the start of 2020, more than 4.54 billion people were using the internet globally which is about 59% of the global population while active social media users surpassed the 3.8 billion mark which is about 49% of total population of

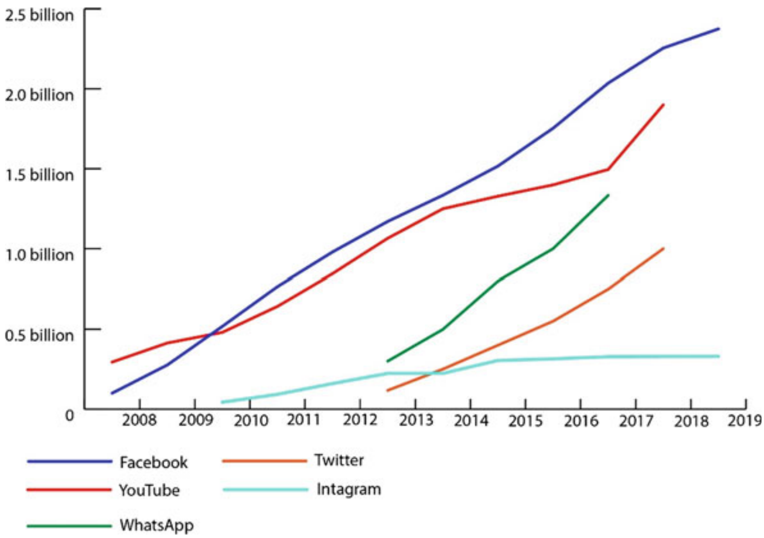

Fig. 3 The increment of the global usage of the different social media applications

the world ("Digital 2020," 2020). Figure 3 shows the increment of the global usage of the different social media applications (social media platforms and messenger aps) within the period of 2008–2019 ("The rise of social media," 2019) and Fig. 4 presents the evolution of technology and social media (social media platforms and messenger apps) (Alrubaian et al., 2018; "Gradient Facebook Features Timeline Infographic Template," n.d.; "MGA IT Web Tutorials: MGA," n.d.; "The Reverse Evolution of Social Media Platforms," 2017; Hynson, 2018).

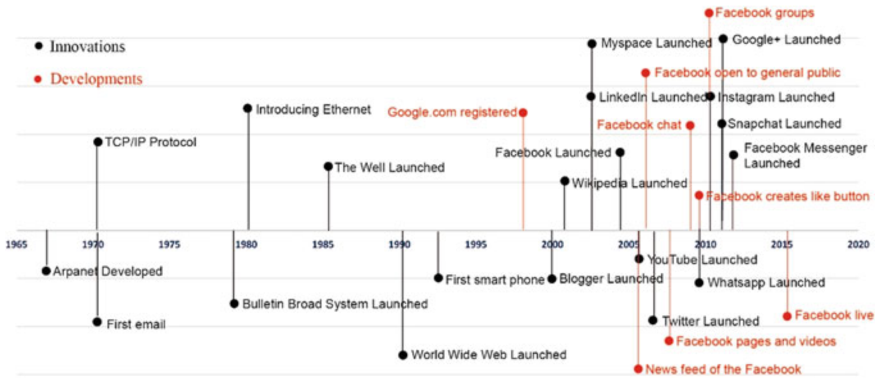

Fig. 4 Evolution of technology and social media

4.2 Sri Lankan Context

According to island wide survey carried out by Asia Pacific Institute of Digital Marketing—APIDM Sri Lanka in November and December in 2019, it can be concluded that the social media has been spread widely in Sri Lanka too and various social media platforms and messenger apps are currently being used by the Sri Lankan community. Figure 5 illustrates the general usage of social media applications (social media platforms and messenger apps) in Sri Lanka for the year of 2019. ("Digital Outlook 2020 Report," 2020).

A questionnaire survey has been conducted in 2019 to investigate the current condition in the community response over the technological applications and the existing mechanisms in disaster Early Warning mechanism in Sri Lankan context (Shehara et al., 2020). The survey was carried out within the 10 *Grama Niladhari*

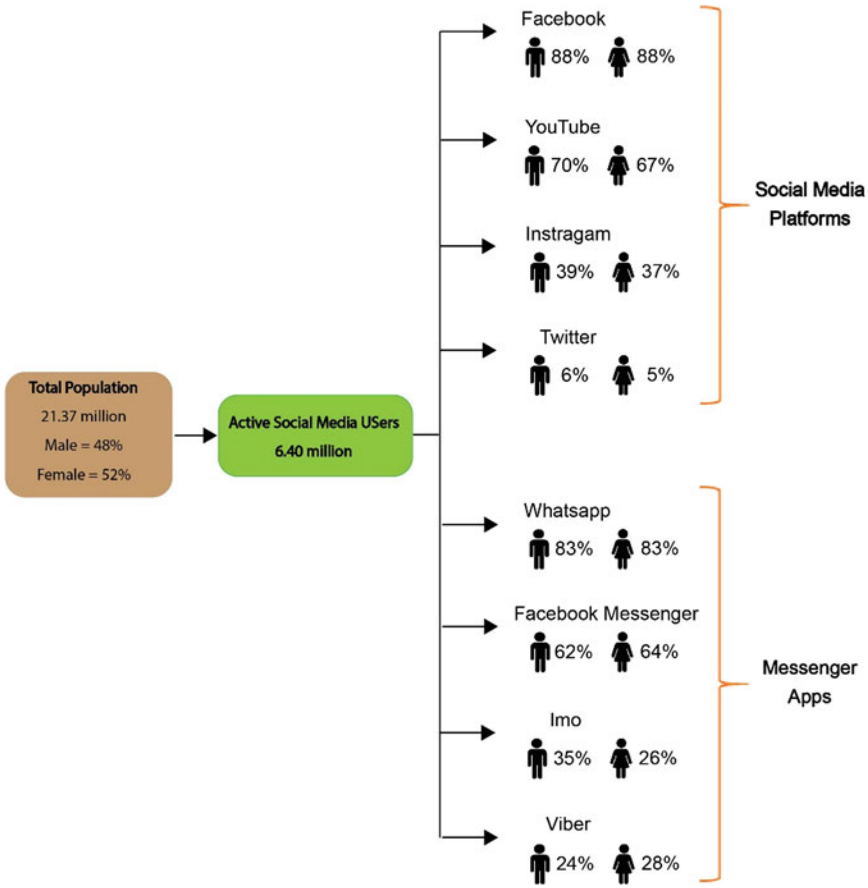

Fig. 5 Usage of social media applications in Sri Lanka in 2019

divisions in Sri Lanka, and 323 responses were collected and analyzed. Through that survey, it has been identified that 32% of the responders have been using social media platforms frequently in daily usage while 68% of responders have not been using social media platforms in daily usage. And also, the level of frequency of using social media platforms by the responders based on the age category has been identified in this study and the overall survey was summarized that there is a low frequency of using modern technological platforms by the community and low adaptability of them towards modern tools and technologies (Shehara et al., 2019a, 2019b, 2020).

5 Use of Social Media During Disasters

5.1 Global Context

Information and communication technology (ICT) is commonly used widely during different phases of disaster (Kabra & Ramesh, 2015; Ocen et al., 2016). As an emerging information and communication technology, new attention has been drawn to use the social media by the general public as well as the various organizations during recent worldwide disasters by generating and disseminating important disaster-related information (Sarcevic et al., 2012). Since social media expresses one's view in real time, it is very attractive tool for disaster management because both victims and officials can put their problems and solutions in real time at the same place and it has been studying by various developers, academics, government officials and corporations (Singh et al., 2019). Social media can be adopted in almost all the phases in Disaster Risk Management Cycle (Houston et al., 2015a; Mauroner & Heudorfer, 2016). Through the literature survey, it can be able to identified that several instances in which social media has been critically involved during various catastrophic hazards such as Earthquake (Jung & Moro, 2014), Flood (Bhuvana & Arul Aram, 2019), Hurricane (King, 2018), Tsunami (Peary et al., 2012), Volcano Eruption (Nigam, 2010), Wildfire (Starbird & Palen, 2010), Drought (Wagler & Cannon, 2015), Terrorism (Oh et al., 2013) and Violent Crises (Li et al., 2015).

Researchers have been conducted various types of studies in the context of use of social media during disasters considering as a key component in DRR&M (Jayasekara, 2019). A study carried out by the Feldman et al. (2016) has revealed that the age is the central factor in deciding the source (traditional media and modern media) to receive the risk information. Most of the studies have concluded that the social media has the potential to contribute to a rising engagement of the population in strategic in various phases of disasters due to its predominant impact on the distributing of disaster related information (Liu et al., 2020; Mauroner & Heudorfer, 2016). Several studies have been conducted out by analyzing data from the case studies on use of a particular social media applications (social media platform or messenger app) such as Twitter during disasters (Bruns & Burgess, 2014; Murthy & Longwell, 2013).

5.2 Sri Lankan Context

Disaster Management Centre (DMC), which is the leading risk management agency in Sri Lanka are used system called "Disaster and Emergency Warning Network" (DEWN) to disseminate warning messages (SMS) among the public The DEWN system issues alert "through a secure computer application where the text, geographical area and the recipients (individual or groups) can be selected for the message". Due to region specificity of the DWEN system, it was not a successful disaster communication method throughout the 2016 flood in Sri Lanka. During the flood, which occurred in Sri Lanka in May 2016, social media was the main source of communication and Facebook was the most popular social media platform. Considering COVID-19 pandemic situation in Sri Lanka, social media has been playing a vital role to disseminate the risk information and updates about the COVID-19 pandemic to the general public. Many of Facebook pages, Facebook groups, WhatsApp groups has been created with the purpose of disseminating COVID-19 information by the various stakeholders such as news media, community groups, influencers, researchers, etc. (Jayasekara, 2019; Microimage, 2014; Paulraj, 2016).

A survey has been carried out in 2018 to reveal the applicability of different social media application (social media platforms and messenger apps) in the context of Early Warnings disseminating in Sri Lanka (Jayasiri et al., 2018). That survey has been shown that Facebook and WhatsApp are the most prominent and effective social media applications in terms of communicating and disseminating early warning messages via mobile phones.

6 Reasons for Using Social Media During Disasters

As an evolving and emerging communication channel, particularly, social media has become a very important media communication which plays the complimentary role which was previously played by traditional media (Takahashi et al., 2015). Several reasons can be identified from the literature that led to the popularity of social media to communicate disaster risk information among the general public and other stakeholders.

Social media gives a multi-directional information flow which is unidirectional for traditional media. Since traditional media provides a one-way communication system, only sources (content creators) can disseminate information to the general users. But in social media, both content creators and general users can participate in the communication because of the two-way communication mechanism offered by social media (Houston et al., 2015a). Due the two-way communication mechanism provided by the social media multiple contents can be shared by having one-to-one, one-to-many, many-to-many communications and with this facility, victims of disasters can present the real time problems and situation to the relevant authorities by providing eyewitness perspectives through video, photos, or texted message and it is very much important to authorities to take necessary reactions (Freberg et al., 2013). And also, this is caused to increase the situational awareness which means the humans understanding what is occurring in their surrounding environment, in this case a disaster event. Because users have the ability to take photographs, videos and conduct conversations almost in real time and enabling the dissemination of information and communicating with loved ones and authorities (Luna and Pennock, 2018).

Social media has a higher capacity to reach the public than traditional media and with that capability relevant organizations (disaster management agencies) and organizations can be able communicate with broader community via social media (Bruhn et al., 2012; Keller, 2009; Kim et al., 2016). Many of studies have been proven the inadequate capacity of the traditional media in order to satisfy the community-wide information sharing and communication needs of different parties during major disasters (Chan et al., 2006; Huang et al., 2010; Jaeger et al., 2007). Cascading impacts such as power breakups, telephone line breakups can be occurred with the disasters and due to that reason communicating via traditional media might be difficult. In this context social media platforms plays a prominent role because victims in the disaster zones and people out of the disaster zones can be relied on the social media without aforementioned utilities to aware about the situation (Takahashi et al., 2015). And also, the users can connect to the social media directly via any portable devices such as smartphones, tablets, smart watches and laptops (Velev & Zlateva, 2012). Therefore, social media can be used more easily in times of disaster than using traditional media.

Social media provides special additional services which can be used in disaster situation. In 2013, a new service called Twitter Alerts was launched by Twitter to prioritize information from reputable organizations during emergencies when other means of communication are not available ("Twitter Alerts," 2013). And also, the Safety Check was launched by Facebook in 2014 as a service that allows users to communicate that they are secure and check the status of their family members, friends and associates during a crisis ("Introducing Safety Check," 2014). Due to the coronavirus outbreak occurred around the world Facebook has updated its facility to mark Facebook posts with COVID-19 tags and with that facility, it can be highlighted the latest important updates in response to coronavirus because it is helped to reach more people in local community by appearing more visibly in different places on Facebook ("Mark Posts With the COVID-19 Tag," 2020). With those facilities provided social media has become a popular channel in disaster risk management. And also, Facebook has introduced many other features to keep safe the community and provide correct information during the COVID-19 global pandemic such as Facts about COVID-19, Global Reminders to Wear Face Coverings, Expanding Blood Donations Feature, Sharing COVID-19 Symptom Maps and Expanding Survey Globally to Help Predict Disease Spread, Connecting People to Well-Being Tips and Resources, New Tools to Help Health Researchers Track and Combat COVID-19 ("Keeping People Safe and Informed About the Coronavirus," 2020a). Figure 6 graphically illustrates that how the aforementioned special services appeared on social media.

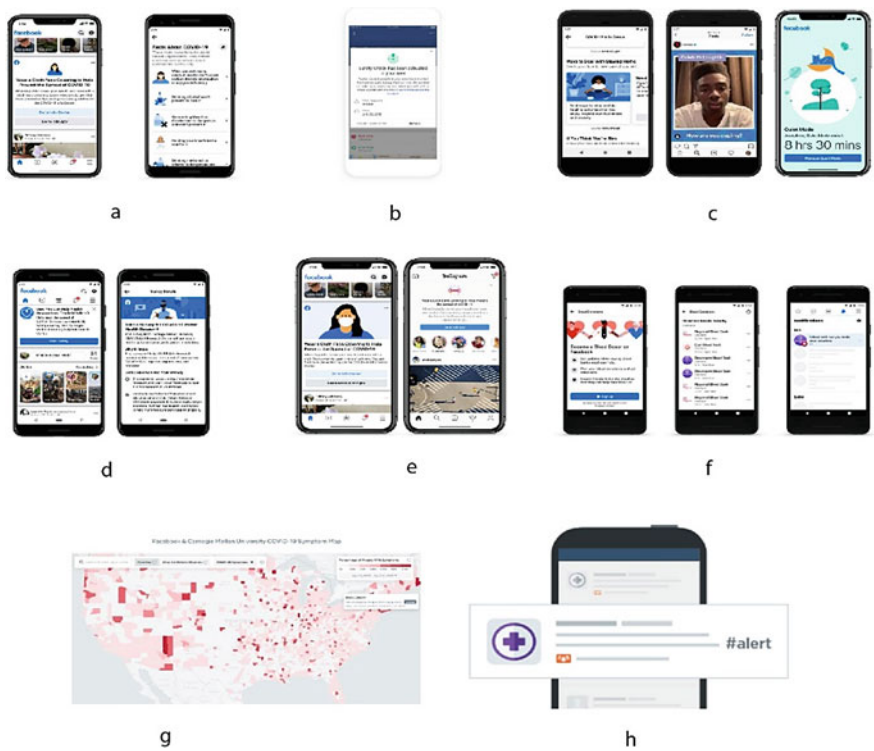

Fig. 6 Special services provide on social media in the context of disasters **a** Facts about COVID-19, **b** Safety check, **c** Connecting people to well-being tips and resources, **d** New tools to help health researchers track and combat COVID-19, **e** Global reminders to wear face coverings, **f** Expanding blood donations feature, **g** Sharing COVID-19 symptom maps, **h** Twitter alerts expanding survey globally to help predict disease spread ("Keeping People Safe and Informed About the Coronavirus," 2020b)

Social media offers a means of contact not only within affected regions, but also between affected regions and the rest of the world. With that facility social media plays an important role in raising awareness and coordinating and generating relief efforts (Landwehr & Carley, 2014; Takahashi et al., 2015). According to the literature not only the individuals but also the governmental, non-government organizations (agencies) have been used social media in the context of disaster risk management (Beneito-Montagut et al., 2013; Veil et al., 2011). With the evolving of the social media the aforementioned agencies have been tend to communicate disaster related information in better way in terms of communicate quickly, be credible, be accurate, be simple, be complete and communicate broadly (Freberg et al., 2013).

7 Developing a Conceptual Framework for Use of Social Media During Disasters

7.1 Importance of Developing a Conceptual Framework for Use of Social Media During Disasters

Preventing new and reducing existing disaster risk by introducing strategies to avoid and mitigate exposure to hazards and vulnerability, to improve response preparedness and recovery, and thereby to enhance resilience is the main goal of the (SFDRR 2015–2030) which was presented to attain its expected outcome ("Sendai Framework for Disaster Risk Reduction 2015–2030," 2015). The effective use of social media can be caused to improve the implementations of the disaster risk reduction strategies (Huang et al., 2010). Considering the current condition of the use of social media in disasters, several challenges and barriers can be identified which are caused to reduce the effectiveness of this context in term of accessibility, reliability, advanced usage etc. (Lovari & Bowen, 2020). According to the study carried out by Houston et al. (2015a) a comprehensive framework for the utilization of social media in disasters has been missing in literature. Such a framework can be used to identify the future improvements and the implementations of the social media in disasters. Also, this framework would be helpful to identify the existing gaps and the bottlenecks of the social media usage in disasters (Houston et al., 2015a). With continued developments in social media practices, technological advances and changes in online behaviors, it is important to provide relevant, contemporary and informative conceptual framework (Gray et al., 2016).

Considering the aforementioned, in this study such a framework for using of social media in disasters is proposed which has been developed around the "Actors" and the "Actions" in the context of the using social media in disasters. Here, any kind of users who use of social media in disasters are called as the Actors and the various uses of social media in different phases of a disaster is called as "Actions". In order to develop this proposed framework, a thorough literature review was carried out which including disaster related reports by the governmental and non-governmental organizations, scientific publications and the other online available sources such as websites, blogs etc. Google search, Google scholar and ResearchGate were basically used to find the relevant literature by searching through the keywords related to this study.

7.2 Identification of the Users of Social Media During Disasters

Several studies illustrated the different types of users who use social media in disasters to communicate disaster related information with others (Gray et al., 2016; Houston

Table 2 Definitions of the user categories who use social media in disasters (Houston et al., 2015a)

User category	Definition
Individuals	In general individuals are the people such as private citizens who do not use social media in disasters as a representative of another association, such as a government or an organization
Communities	Communities included groups of people linked to geographical areas such as communities or villages, as well as groups of people who share information, values, standards, preferences, and experiences and who may or may not share a common geographical area
Organizations	Organisations are structured groups of people that are responding to, affected by, or external to the disaster
Government	Governments include authorities and government departments and agencies at the federal, state, and local levels
News media	Media include organisations, such as those that are large or small, and those that are traditional or new in nature. Examples are a local community blog, a state newspaper, national television broadcast networks and international news organisations

et al., 2015a; Takahashi et al., 2015). Through examining those studies, various categories of users can be identified such as Individuals, Organizations (Governmental, Non-Governmental, Non-Profit), News Media, Journalists, Celebrities, Community groups, Researchers. Study carried out by Houston et al. (2015) has defined some of the user categories who use social media in disasters as showed in Table 2.

In this study, individuals have been divided into two categories according to their location during a disaster whereas within or without the disaster-affected area. Therefore, by examining the literature, several sub categories of individual users of social media in disasters can be identified such as affected people, non-affected people, journalists, celebrities etc. (Takahashi et al., 2015). Therefore, individual users of social media in disasters can be break into two such as influencers (influential social media content creators) and non-influencers (social media followers). In the context of the social media using in disasters, influencer can be defined as a user who seems to have the greatest influence on disaster-related information communication (Kongthon et al., 2014). According to the study carried out by (Abedin & Babar, 2018) regarding the use of Twitter during Australian Bush Fire in 2014, social media influencers have also actively participated to emergency information dissemination via their social media applications (Twitter). That study has revealed that social media influencers play a crucial role in communicating information with the general community through social media applications. Non-influencers (social media followers) are those that either directly or indirectly obtain disaster related from prominent social media content creators. Majority of those who use social media during disasters are followers and they use social media to exchange disaster information rather than produce it (Hall & Park, 2012; Palen et al., 2010; Reynolds & Seeger, 2012).

Different community groups such as group volunteers, researchers, philanthropists etc. have been emerged during disasters to share up to date information with the general public via social media. Administrators of this public community groups have received their information from various authorized valid sources such as Meteorology Department, State Emergency Service, Police Departments, Local councils and News Media and distribute them among the general public. And also, those community groups have published near-real-time information from the general public who use social media because they have also posted different information and problems such as up-to-date information on road closures, asked for help and advice, etc. By publishing these kinds of information, agencies and other relevant parties could be able to identify the real problems and give them solutions immediately (Bird et al., 2012).

As previously described in this study, in the context of traditional media, two separate users can be identified either as content creators or consumers because traditional media typically provide a one-way communication whereas individual media sources communicate information to a large number of individual users. But with the emergence of social media, since it provides a two-way communication, all the users can create or consume the content because social media. Hence in the context of the social media, the conception of who or what constitutes a user is less obvious. Hence, the idea of who or what constitutes a user is less apparent in the sense of social media.

All the aforementioned social media users can be categorized into two main sections named community and agencies where all the individuals (influencers, non-influencers) are belong to the community and all the governmental and non-governmental organizations and news media are belong to the agencies section. Most of these agencies deal with the specific set of disaster operations and specializes in their professional domains. And also, by the examining the literature, several types of interactions can be recognized among the users of social media in disasters such as interactions among agencies, interaction between agency to community and interaction among communities (Ahmed, 2011; Kim & Hastak, 2018).

7.3 Identification of the Uses of Social Media During Disasters

As previously described in this chapter, social media can be adopted in almost all the stages of a disaster which has been illustrated by the Disaster Risk Management Cycle (DRMC). Through investigating the literature, several uses of social media in disaster can be identified in each disaster phase such as Pre-Event (e.g. to communicate disaster preparedness information and early warnings nationally or regionally), Pre-Event to Event (e.g. to detect and signaling of specific hazards locally), Event (e.g. to provide updated information who are in disaster affected area, to inform about the family members and friends who are not in disaster affected area, to request and send help and assistant), Event to Post-Event (e.g. raise the awareness about the donations, reliefs and mobilize volunteers and coordinating them, to express emotion and sympathy, to provide and receive information to discuss about disaster response and recover and rehabilitation), Post-Event (e.g. to discuss socio-political and scientific causes and implications of and responsibility for events) and Pre-Event to Post Event (e.g. consolidate lessons learnt to develop new/improved social media applications) (Du et al., 2019; Fang et al., 2019; Gray et al., 2016; Houston et al., 2015a).

7.4 Development of the Conceptual Framework

This section explains the proposed framework for using social media in disasters which has developed with the aid of the facts gained through the literature review. Figure 7 presents the graphical representation of the preliminary framework which was developed based on the categories that identified related to the topic through the examining of the literature. It has developed mainly under the two main categories as described previously in this study namely "Actors" and "Actions".

Under the "Actors" category, the main indicator is the Users. Users can be introduced either as responders or producers. Because social media provides two-way communication, therefore, every subcategory belongs to the users can both provide and receive the disaster-related information via social media. Community and Agencies are the two main categories of Users. Government, Organizations (Non-Governmental Organizations and Non-Profit Organizations) and News Media are belonged to the Agencies category. As mentioned previously in this chapter, the Community can be divided into two subcategories such as Groups and Individuals. Volunteers, philanthropists, researchers and several other teams of individuals

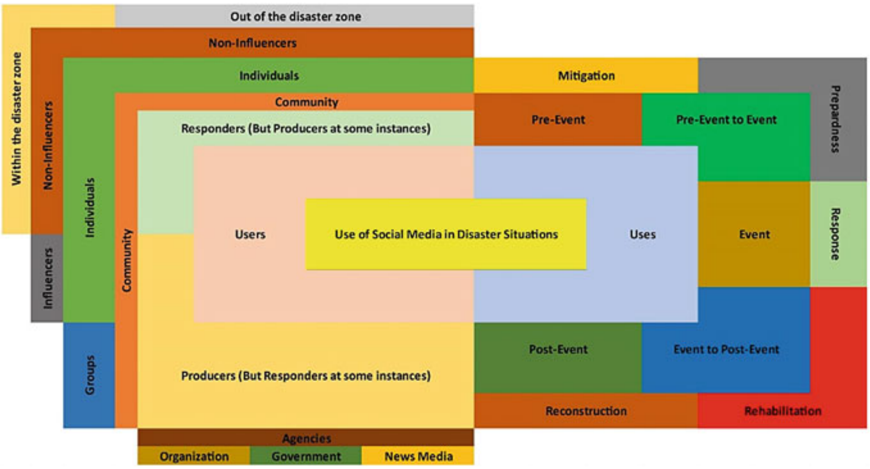

Fig. 7 Graphical representation of the proposed preliminary framework

who have been gathered with the purpose for the disaster related activities such as early warning disseminating, providing reliefs and aids, research purposes etc. are belonged to the Groups subcategory under the Community. According to the literature survey, use of social media such as maintaining Facebook community groups and pages, Twitter accounts, WhatsApp groups for the disaster related purposes by these Groups can be identified. And also, the two types of Individuals such as Influencers and the Non-Influencers can be identified from the literature. Influencers can be identified among the Individuals according to the degree of the influence that they make on the disaster-related information dissemination via social media. As the last mile, Non-Influencers can be separated into two accordingly their location such as Within the disaster zone and Out of a disaster zone.

Under the 'Actions' category, the main indicator is the Uses. Figure 7 illustrates that there are different Uses of social media in every phases of a disaster as described previously in this chapter under the Disaster Risk Management Cycle.

Figure 8 graphically represents the several types of interactions among the Users of social media that can be identified in the context of using social media in disasters. As previously described in this chapter three types of interactions can be identified such as interaction among the agencies, interaction between the agencies and community, interaction among the communities. And also, Fig. 8 represents the various types of the disaster phases and activities that User can be participated by using social media.

Through the literature, several key facts were identified in the context of the use of social media by the Non-Influencers in disasters. It is very important to identify those key facts because Non-Influencers are the most important part in the context of the using social media in disasters because they are the mostly vulnerable Users due to disasters. Perception of the Non-Influencers about the information received via social media is one of the key facts in the context of using social media in disasters. In order to have a better perception, the quality of the information received via social media should be at a higher level. There are several quality indicators have been identified in past researches (Bird et al., 2012; Freberg et al., 2013) to evaluate the quality of the information received via social media in disaster as listed in below Table 3.

Figure 9 illustrates the integrated framework which has been developed, including the aforementioned quality indicators. Apart from that quality indicators, several other key facts have added to Fig. 9, which were identified during the literature survey. These are very important in the context of using social media by Non-Influencers in disasters (Bird et al., 2012). Identification of the general use of social media by the Non-Influencers is one of the key facts because, with that information, the ability to use social in disasters by the Non-Influencers can be identified. And also, it is a necessity for identifying the existing method (traditional media) to communicate disaster-related information and their problems. To implement the best social media practices in disasters, it is important to understanding these prevailing methods. And also, the Non-Influencers' awareness about the capabilities of using social media in disasters and their expectations by using social media in disaster are the two other

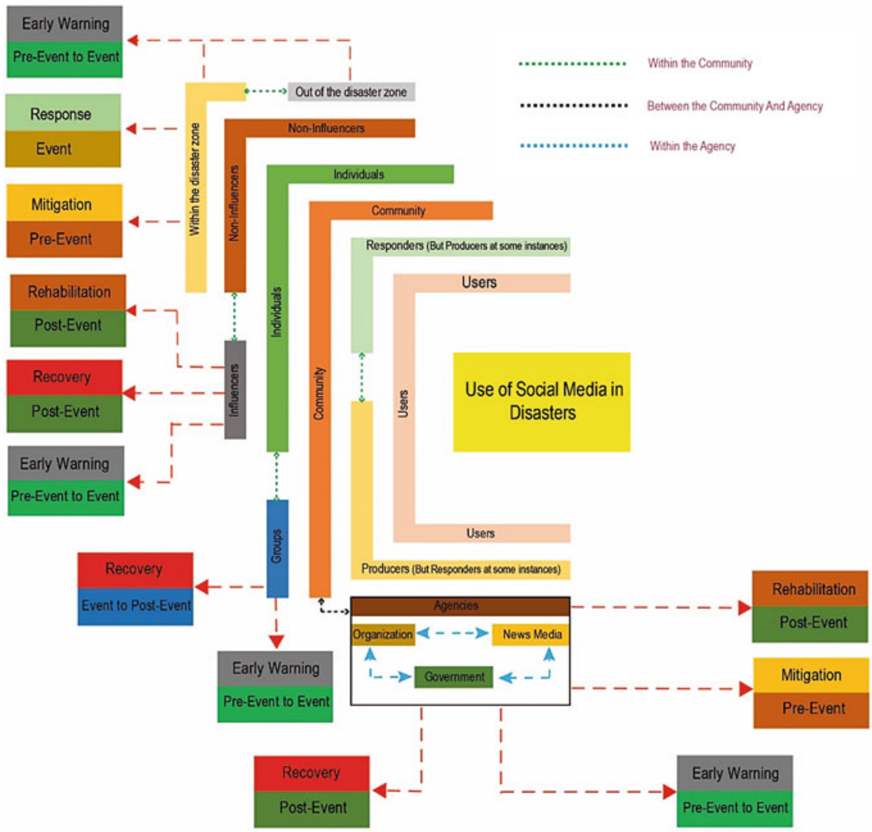

Fig. 8 Interactions among users and the activities in DRMC that that user can be participated by using social media

key components in this context. With those key facts, a comparison can be conducted between traditional media and social media by the Non-Influencers to identify the best practice and channel that can use in disasters.

8 Discussion

Currently, the possibility of hazards by the global community has been increasing and the devastating impact that can be occurred due to those hazards has been also growing up. Hence with this rapid occurrence of various hazards day by day, there is a world-wide necessity to impose appropriate measures to reduce disaster risk and minimize the disaster-related economic losses and damages as emphasized on the (SFDRR 2015–2030). Communication and dissemination of disaster-related information are

Table 3 Quality indicators to evaluate the quality of the information on social media in disasters

Quality Indicator	Explanation	Reference
Accuracy	Ability to verify the information	(Freberg et al., 2013)
Timeliness	Timeliness refers to the expectation of time for accessibility and information availability Timeliness can be measured as the time between the expectation of information and the availability of it for use	(Loshin, 2009)
Usefulness	This is about learning what sources of knowledge people use and how people use information to make sense of their lives and circumstances	("Use of Information | Encyclopedia.com," 2020)
Reliability	The possibility that information is accurate and that the value of information is reliable in order to explore the degree of risk information consumers should incur when using information	(Koops, 2004)
Simplicity	Ability of the user to realize the full potential of the meaning and the interpretation of the information	(McAuley, 1993)
Perfectibility	The degree to which there is no shortage of information and adequate breadth and depth for the task at hand	(Chai et al., 2009; Wang & Strong, 1996)

one of the key components in Multi Hazard Early Warning Mechanism which can be considered as a measure in Disaster Risk Reduction (Basher, 2006; Dutta et al., 2015; Gwimbi, 2007). Proper delivering of disaster-related information by using developed technological applications can be significantly impacted to the society in terms of reducing damages and losses over lives and properties. This concern has been illustrated under the seven global targets of the Sendai Framework for Disaster Risk Reduction 2015–2030. And also, in the context of the Disaster Risk Management and the Disaster Risk Management Cycle, various disaster related risk communication (Disaster Risk Communication) processes can be linked to the activities which are taken during each phase of the Disaster Risk Management Cycle (Mauroner & Heudorfer, 2016). Communication channels can be considered as the major component in Disaster Risk Communication because it is necessary to deliver accurate risk information timely to a broader community (Freberg et al., 2013; Siddhartha, 2017).

Social media is a prevalent and emerging communication channel that enables users to create, consume and share information with a broader community. As the lessons learnt from the previous disasters which have been reported all over the world, it is demonstrated that there is a high potential to adapt social media in disaster risk management as an advanced communication channel by supporting for communication and dissemination of disaster-related information to a broader community (Luna and Pennock, 2018). Compared to traditional media, as described

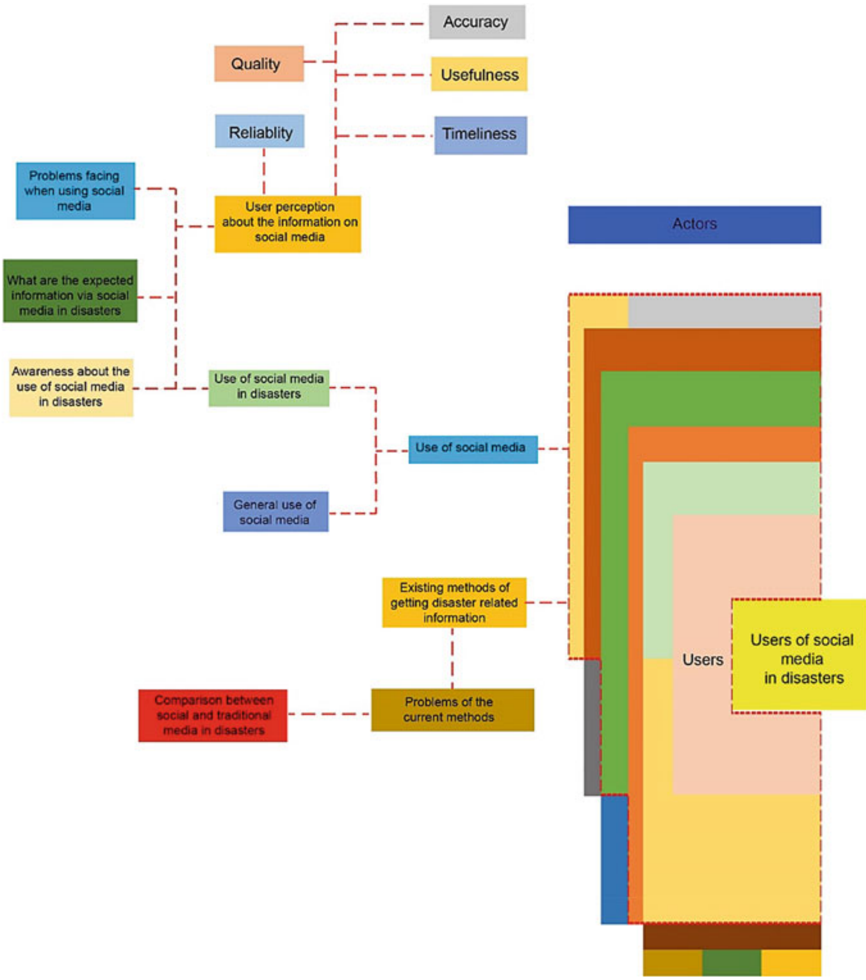

Fig. 9 Integrated framework

earlier in this chapter, social media has superior and developed features that make it popular among the community to use social media in disasters.

When examining the previous studies and research literature regarding the use of social media in disasters, it could be able to identify that development of a conceptual framework for using social media is very important to facilitate the development of the social media usage in disasters and improve the implementations of the practices of using social media in disasters by identifying the existing gaps and problems of using social media in disasters and enhancing the scientific studies and researches in this matter. In this study, such a conceptual framework has been proposed that developed through a comprehensive literature review which has built with the base of Users of social media in disasters and the Uses of social media in disasters. Several key facts in the context of Users and Uses of social media in disasters have been considered to develop that framework (Gray et al., 2016; Houston et al., 2015a).

9 Recommendations

As a future implementation of this study, it is expected to identify the existing practices of using social media by the Sri Lankan community in disasters. In order to do that, a questionnaire will be developed based on the proposed conceptual framework of this study and will be circulated among the general public in Sri Lanka. By analyzing the results that would be obtained from that questionnaire, the existing condition of the use of social media in disasters by the Sri Lankan community will be identified with its prevailing gaps problems. And also, it is expected to discuss strategies that would be helpful in future to bridge the existing gaps and enhance the future implementation of social media in disaster events of Sri Lanka.

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An Analysis of the Downstream Operationalisation of the End-To-End Tsunami Warning and Mitigation System in Sri Lanka

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Abstract An end-to-end tsunami early warning and mitigation system (TEWMS) is typically divided into upstream and downstream processes, the former involved with the detection and evaluation of a tsunami threat, and the latter with warning dissemination and evacuation. The operationalisation of the downstream mechanism is analysed in this paper, using the tsunami early warning system in Sri Lanka as a case study. Data collection and the subsequent thematic analysis method were underpinned by a conceptual framework for tsunami early warning systems that had been developed previously by the authors. The results of the study revealed gaps in the downstream operationalisation of the end-to-end tsunami warning and mitigation system in Sri Lanka, including a lack of synergy between the standard operating procedures (SOPs), inadequate technical and human resources, weak linkages to village level disaster management committees, a lack of sectoral integration in some instances, and public complacency towards drills. Recommendations were provided to develop a synergised SOPs for the tsunami warning system in Sri Lanka. The study provides a unique insight into the current status and challenges associated with implementing an effective tsunami warning system at the sub-national level.

Keywords Case study · Downstream · Sri Lanka · Tsunami · Early warning

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1 Introduction

Warning systems are complex because they bring together many areas of expertise, including science and engineering, governance and public service delivery, disaster risk management, media and communication, and public outreach. As a consequence, the development and maintenance of an effective warning system demands contributions from, and coordination among, a wide range of individuals and institutions. Without the involvement of all stakeholders—state authorities and government institutions from various sectors and at all levels, the communities at risk, NGOs and the private sector—the early warning system will not be effective. After the tragic Indian Ocean tsunami (IOT) in 2004, an end-to-end tsunami early warning and mitigation system (IOTWMS) was established in the Indian ocean region targeting all the countries exposed to the disaster. The system was developed to detect the tsunami wave before its arrival and warn people to evacuate to safer places. Starting from the regional level, the warning mechanism goes through national and local stakeholders until the warning is disseminated and the affected communities are safely evacuated.

A variety of guidelines and frameworks have been developed to support countries in implementing the IOTWMS at the national and sub-national levels. However, responsibility for implementation remains under the purview of each country. Due to the diversity among the twenty eight Indian Ocean countries that are covered by IOTWMS, including factors such as land area, population size, exposure to tsunami and local capacities, as well as the large number of actors engaged at the national and sub-national levels, there are wide variations in how the system is implemented. Once the regional tsunami service provider (TSP) sends the warning alert to a country, it is up to each country's national warning centres to process the warning information and alert the public. It is often not clear how the decisions are made, or how the warning and evacuation orders are disseminated at the country level.

This study was undertaken to investigate and analyse how the decision-making process and warning dissemination is carried out in countries. There are two significant phases of tsunami early warning that occur at the country level. Firstly, the interface arrangements, whereby the regional warning, along with any national information sources, are evaluated and a decision is taken as to whether or not to evacuate. Secondly, the downstream where warning information or an order for evacuation can be disseminated to the public and people are evacuated to safer places. Two countries in the IOTWMS, Indonesia and Sri Lanka, were selected as the cases for the study. The findings were published in research papers, developed into policy briefs and some of the recommendations were implemented at a policy or practical level (Amaratunga et al., 2019; Haigh & Amaratunga, 2018; Haigh et al., 2020; Rahayu et al., 2019; Sakalasuriya et al., 2018). The focus of the current paper is to provide an analysis of how the downstream phase of the IOTWMS operates in the Sri Lankan context.

This chapter begins with an introduction to tsunami early warning systems, including IOTWMS and the various stages of an end-to-end warning system, from the upstream, through interface arrangements to the downstream. Section two describes a conceptual framework identified from a literature review. This underpinned the study's data collection and analysis, which are explained in section three. The fourth section present the results, as well as some of the key gaps to emerge. The final section of the chapter concludes with a set of recommendations that could inform an improved implementation of the IOTWMS in Sri Lanka, while also setting out areas for future research.

2 Tsunami Early Warning Systems and Downstream Mechanism

Among the efforts to prevent the disastrous impact on human lives, early warning systems were introduced in the regions and countries prone to tsunami inundations, with the main aim of alerting people for evacuation prior to the impact (Cecioni et al., 2014). These interventions became significant and received much attention after the 2004 Indian ocean tsunami, which resulted in over 230,000 deaths across 14 countries (UNESCO & accessed in, 2018). While using the scientific tools to predict the impact of the tsunami, the system also involves socio-political aspects of decision making about emergencies and responding to warnings. An end-to-end tsunami early warning and mitigation system can be divided into three main phases, namely upstream, interface and downstream (Sakalasuriya et al., 2018). The upstream is more concerned with the technical aspects of detecting the threat and communicating that information from a TSP to a National Tsunami Warning Centre (NTWC) (Wächter et al., 2012; IOC/UNESCO, 2015b). During the early stages of the present study, the interface was defined to be taking place at the national level, which includes decision making to warn the public, disseminating the warning from national to local level, and until the order of evacuation is officially issued (Haigh et al., 2020). After warning information or an order for evacuation are issued by the national body, there are different channels by which the information is passed down to the public. This last phase is known as the downstream mechanism (IOC/UNESCO, 2015b; Bernard & Titov, 2015). Since the decision for warning is taken and order for evacuation is given within the interface, the downstream process is defined in the present study as starting from after order of evacuation given. The main action points within downstream are publicising of the warning information and evacuation order, and then evacuating the public (Sakalasuriya et al., 2018). According to Lendholt and Hammitzsch (2011), downstream of an early warning system includes warning dissemination, information logistics, warning and alert services, distribution channels and message reception. The process ends when the evacuated people are safely returned to their homes, which is also the end point of the total tsunami warning chain (IOC/UNESCO, 2015b).

The downstream mechanism can vary across countries, depending on a range of economic, social, political and spatial dynamics. Despite these variations, a commonality across countries' downstream processes is the involvement of both technical and social challenges (Boulos et al., 2012; Minsch et al., 2012). Technology is used to receive, assess and disseminate information, interlinked with human and social components of decision making and responding. On the other hand, it is at this stage of the warning system that different kinds of national and local, and public and private actors come together to convey the warning and evacuation information to people. Of the four key elements of an early warning system (UNISDR, 2006), it is the 'dissemination and communication' and 'response capability' elements that are especially relevant to the downstream mechanism. At this level, sending the warning to all those at risk, in a clear and easily understandable manner, are critical requirements (Spahn et al., 2010; Sutton & Woods, 2016). It is also necessary to keep the evacuation plans up to date (Ai et al., 2016), improve local capacities (Fanany et al., 2010) and prepare people for emergencies (Hatthakit & Chaowalit, 2011).

3 Literature Review; Analytical Framework for Downstream of Component Tsunami Interface

As mentioned in the introduction to this chapter, the study on which this paper is based was carried out in two sections: the first focused on the interface arrangements; and, the second on the downstream of the TEWMS. At the initial stage of the study, a literature review was carried out to understand the requirements and features that should be taken into consideration within the interface mechanism of a tsunami early warning system. The interface study was then carried out based on the conceptual framework produced through the literature review, which included following nine concepts (Sakalasuriya et al., 2018).

1. Decision-making mechanism;
2. Clearly defined actors;
3. Centralised vs decentralised approach;
4. Standardisation of interface;
5. Technical capacity
6. Human capacity;
7. Spatial and socio-cultural aspects;
8. Vertical and horizontal coordination; and
9. Formal and informal communication mechanisms.

For the second part of the study, the literature review was extended to cover the dissemination of tsunami early warning and downstream arrangements. The included updating the nine original concepts to reflect the widening scope, as well as three additional concepts that are specific to the downstream. In order to that, the knowledge related to downstream process in the already gathered literature, were mapped against the nine concepts. The new knowledge that could not be categorised under any of the concepts were formed into new concepts. There were five new concepts in the downstream framework, and concept on (de)centralisation from interface framework was removed as it was found to be less relevant to downstream. The result was an expanded conceptual framework that encompassed twelve concepts that are particularly relevant to downstream of TEWMS. Once the downstream conceptual framework was formed more research studies were explored using the words within the framework, while also using snowballing to expand literature review; i.e. using the reference lists of the articles already in collection (Lecy & Beatty, 2012).

3.1 Decision Making Mechanisms

Decision making is defined as a way of coming to conclusions by comparing judgements against standards (Baron, 2004). According to Platt's typology of decision making in disasters, the operational decisions made for relief and recovery are important for decision makers at the district level and below. These must be made quickly and under pressure to respond to crisis situations, and ideally will be made according to proven protocols and rehearsed in advance of the disaster (Platt, 2015). A people-centred approach is necessary to transform the traditional practices of early warning systems into an efficient mechanism of decision making (de León et al., 2006). This is also highlighted in the four elements of early warning systems introduced by United Nations International Strategy for Disaster Reduction (UNISDR). In order to encourage local decisions and community participation in an early warning system, the governance system should be well developed and effectively institutionalised (UNISDR, 2006). In developing countries that are prone to disasters, the decision making at the lower levels of governance structure is often influenced by higher political and monetary powers, and adequate authority is sometimes not given to local levels (Sylves & Búzás, 2007). Empowering the local communities and lower level leadership with the tools, knowledge and expertise to take effective decisions, will contribute to successful outcomes in case of an emergency situation such as tsunami inundation. At the same time, there is a need for sound institutional mechanisms at the local level to put into practice the policy set by the national and international level actors (Basher, 2006).

3.2 Clearly Defined Actors and Their Roles

Having clear guidelines on the roles and responsibilities of all stakeholders is key in saving lives and property in disaster preparedness. UNISDR (2006) identifies eight groups of key actors important for an early warning system in general: communities, local governments, national governments, regional institutions and organisations, international bodies, NGOs, the private sector, and the science and academic community (UNISDR, 2006). However, in different countries, the actors involved in a tsunami early warning system can vary depending on a number of country specific factors, including geo-political situation, socio-economics, culture, religion, customs and traditions. Basher (2006) suggests that an early warning system that addresses all different scientific and social aspects should take into consideration non-traditional actors like politicians and community leaders. However, these actors should also be able to take quick decisions under pressure and solve complex problems with limited information and act proactively to minimise the risk to communities (Platt, 2015).

The tasks relating to downstream include disseminating the warning and evacuation information to the public and assisting the public for evacuation to safety. A large array of actors carry information through different channels and take decisions to ensure safe evacuation of all vulnerable communities before the tsunami wave (Raju & Becker, 2013). Typically, this might include provincial/district disaster management organisations, including the media, police and security forces, local governments, community leaders, village committees, religious leaders, welfare workers and the community itself. Having a variety of networks to reach the people is a helpful mechanism to ensure their safety. At the same time, this network should be able to reach diverse communities, keeping in mind the differences in language, culture, traditions and needs (McGinley et al., 2006). Among the vulnerable people there can be urban and rural communities, local and international tourists, or for example, fishermen in deep and shallow seas (Nawaz & Naeem, 2016; Strömbäck & Nord, 2006). It is also important to pay special attention to the people who have special needs, such as the elderly, sick and impaired, young children and pregnant women (Chakraborty et al., 2005).

3.3 Standardisation

Standard operating procedures (SOPs) are the guidelines followed by national and local institutions that contain the bulletins or advisory in case of a tsunami inundation (Nayak & Srinivasa Kumar, 2008). They are agreed by the stakeholders in order to specify the who, what, when, where and how for a tsunami early warning and response situation (United Nations ESCAP, accessed in 2018). It is useful to have clear guidelines for actors at all operational levels, but also capture knowledge from different disciplines to provide those guidelines (Steinmetz et al., 2010). Drawing from that, it is important that each actor, be it individuals or institutions, who take decisions or have responsibility for specific actions within the early warning system, have their own SOPs to deal with an emergency situation. In most countries prone to tsunami, the SOPs are defined as a whole for the entire early warning system. However, it is often not clear which one applies to which phase of the system and often there is confusion about the specific roles and responsibilities (Dominey-Howes & Goff, 2013). Although the national SOP for the main disaster management agency is defined in most countries, they are not properly established for other stakeholders, such as the media, security forces and other government departments. In certain countries, like Pakistan and Timor Leste, the SOPs for district level and below are almost non-existent (Naeem, 2016; Xavier & Araujo, 2016). Previous studies in Sri Lanka have found that the available SOPs at national and departmental levels are not properly integrated into the system, which can result in misunderstanding and inaccuracy, while SOPs are not even defined for the local government level (Premalal & Kodippili, 2016).

3.4 Technical Capacity

Technology is a key element in the early warning system, and varies according to different functions and needs at its different stages. de León et al. (2006) points out that less developed countries are lacking in technical capacities and improving the national and local emergency and disaster technology is key to an integrated approach to the early warning systems. de León also points out that there is a weak linkage between technical capacity and the capacity of the public to respond to an emergency, and therefore it is important to ensure that the technology is properly linked to the community emergency network. According to Spahn et al. (2010), identifying the issues and needs, and designing the technological solutions appropriate to those needs, is an effective method of incorporating technology into the early warning system.

At the national level, advanced technologies are used to receive and process regional earthquake and tsunami information (Dunbar & Weaver, 2008). When it comes to downstream, certain countries will still need evaluation and processing information based on the magnitude of the inundation and the size of the country (Spahn et al., 2010). If the country is large, and the coastal communities are geographically spread across a large area, the tsunami risk can be evaluated for local impact. Therefore, the local disaster management organisations should be equipped with adequate and up-to-date technology to analyse and process the information received from the national tsunami warning organisation. Irrespective of the size of the country, communication technology is a vital component to receive, send and disseminate warning and evacuation information, both vertically and horizontally (Maiers et al., 2005). A wide range of technology is used in countries, including formal and informal announcements, electronic, printed and social media, tsunami towers and sirens. It is important that all technical equipment is functioning, maintained and up to date to meet the emergency needs. At the same time, the adequacy of the technical capacity is also a crucial requirement, as most countries face shortages and inadequacies at the sub-national levels of the warning systems (Robinson & Robison, 2006; Uchida et al., 2011).

3.5 Human Capacity

The first three stages of disaster management cycle, namely prevention, mitigation and preparedness, are very relevant for the early warning system, and they all require the basic function of capacity building for actors involved (Platt, 2015). Disasters resulting from tsunami are highly human centred; the decisions and actions are taken by people. Therefore, all the institutions involved in the tsunami early warning mechanism should have adequate and skilled human resources to deal with the emergency situation (Maiers et al., 2005). In most developing countries, the local level disaster management organisations and community organisations are unable to respond rapidly to disasters due to a lack of human capacity and preparedness (de León et al., 2006; Kapucu & Garayev, 2011). It is important that the responsibilities assigned to individuals in each organisation are reviewed and revised from time to time, focusing on collaboration and solution-based approaches. The human inadequacy, inaccuracy and incompetency can lead to problems in issuing and disseminating the warning (Chatfield & Brajawidagda, 2013). If the key decisions of warning and evacuation are taken by local officials, the local capacity needs to be improved to ensure adequate scientific knowledge and training of technical staff, as well as ensure they are familiar with up-to-date information (Anderson, 1969).

3.6 Spatial and Socio-Cultural

Risk knowledge is one of the four basic elements of an early warning system. It is essential that risk maps and data are available in order to decide on a warning and issue orders for evacuation (UNISDR, 2006). Hazard maps are a useful tool in hazard assessment and mitigation, and can be used to design the evacuation planning, so that safety can be ensured in case of a disaster (Titov et al., 2003). It can also empower the local communities to take actions according to their local needs and using their own resources (Bernard, 2005).

For the countries vulnerable to tsunami disasters, the temporal and spatial dynamics can be taken into consideration in developing the hazard maps (Schlurmann et al., 2010). As highlighted by UNISDR (2006), proper planning and testing is an essential part of the early warning system, and it is important to practise these plans in order to check the reliability in advance of an emergency situation. Preparing the local communities for an emergency is an integral component of this planning. At the same time, risk reduction can be mainstreamed into public policy to increase community participation in key tsunami related activities (Collins & Kapucu, 2008). Education is one such potential area of policy, where tsunami mitigation, preparedness and risk reduction can be mandated under the curriculum. It allows a large part of a vulnerable community to access the early warning information and also helps to engrain an inter-generational culture of awareness (Dengler, 2005). In addition, previous studies have emphasised the significance of indigenous knowledge, socio-cultural values, traditions, practices and beliefs, and diversities of information in an effective early warning system. These can be used to develop community based disaster management tools (McAdoo et al., 2009; Perry, 2007).

3.7 Vertical and Horizontal Coordination

Basher's integrated model for early warning illustrates that an effective early warning is not just a series of fragmented steps, but is a system that successfully combines a number of elements. The sets of elements and their linkages are very important to obtain the desired outcomes (Basher, 2006).

In the case of a tsunami inundation, different individuals and institutions work together and the proper coordination among these stakeholders is essential to bring successful solutions to ensure the safety of people (Taubenböck et al., 2009). Different expertise and knowledge of scientific institutions and academics should combine usefully together with different levels of influence and authority of governance, civil society, media and NGOs (Elliott, 2016). Although risk knowledge and scientific methods develop rapidly to minimise the risk of tsunami impact, managing a healthy coordination among the actors at all levels remains a challenge to many countries. This coordination should be maintained between the national and local actors, among the various national actors and also among various local actors. Unsatisfactory coordination could lead to misinformation among the stakeholders, as well as to the discriminatory treatment of the vulnerable communities (Perry & Green, 1982). Lack of coordination is a common problem found in administrative and political systems, especially in developing countries, due to personal and political needs and expectations, the perceptions of people, and prioritisation in national government policy. Due to this, local level actors, as well as national actors in the periphery, do not clearly understand the central objectives and strategies of the early warning system (InterWorks, 1998). It is through collaborative management of the disaster that extreme disaster events like tsunamis can be effectively managed and the community safety can be maximised (Waugh & Streib, 2006). Collaboration can also be improved by incorporating aspects addressed in some of the other eleven conceptual areas, such as clear SOPs, defined roles for actors and capacity building (Kapucu & Garayev, 2011). While providing the core national level institutions with necessary tools for coordination, the communities should be empowered to feedback their response to local and other periphery organisations, making a direct linkage between the core tsunami actors and the public (Taubenböck et al., 2009).

3.8 Formal and Informal Communication Mechanisms

A tsunami early warning system requires the operation of collaborative communication infrastructure at all levels of making decisions and disseminating information (Wächter et al., 2012). Along with communication between the decision makers and law enforcement, it is important that the general public receives the warning and evacuation orders speedily and accurately (Aldunate et al., 2005). If the communication infrastructure is weak, the public, and especially vulnerable communities, may not receive the warning and evacuation orders given by the authorities. On the other hand, when there is a tsunami threat, the public can be overwhelmed with information from several different modes, and the reliability of this information may be at stake (Taubenböck et al., 2009). Furthermore, the increased use of mobile, internet and social media in the communities can also be useful to disseminate tsunami information promptly (Hiltz et al., 2011; Mersham, 2010).

3.9 On-Going Evaluation

UNISDR guidelines on early warning systems recognise the importance of keeping the response and evacuation plans up to date, and testing the plans for accuracy (UNISDR, 2006). In this regard, it is necessary to test every aspect within a tsunami early warning system to ensure its efficiency, as well as to update it according to the needs of a community. It is unavoidable for some errors in forecasts to occur in any warning system. However, continuous evaluation can minimise these errors by understanding them in advance (Titov et al., 2005). Although public awareness and education is a significant component in the downstream of a tsunami early warning system, it is necessary to introduce alternative innovative approaches for hazard education through research and development (Paton et al., 2008). Maintaining the evacuation routes and signs, as well as updating the evacuation plans based on transport and other development activities, is an essential component of preparedness (Mas et al., 2012).

3.10 Focus on Especially Vulnerable People with Reduced Mobility

The most important action to be undertaken in the face a tsunami threat is the evacuation of people. Due to the limited time available soon after a tsunami warning, all preparations must be made in advance of an event so that people can be moved quickly during emergency (Spahn et al., 2010). It is essential for a people centred early warning system to ensure the safety of all those who are likely to be affected by the disaster. Often, the public's understanding of their risk and vulnerabilities is not adequate (de León et al., 2006). Elderly community members and people with special physical needs may require particular equipment to be carried with them during evacuation. Vulnerable people may also not have any one to support them due to living alone or poverty conditions (McGuire et al., 2007). It is necessary that communities in general, and the relevant disaster management authority at the local level, keep a supply of life-support equipment, mobility equipment and other necessary items to be used in case of a disaster, as the vulnerable community members may require them before, during and after evacuation (Pekovic et al., 2007). A prior needs assessment can determine the kind of supplies needed at a community level.

3.11 Preparation of Logistics After Evacuation

After the people are evacuated to a safer place, keeping them secure and in comfort is a significant component of the downstream process of tsunami early warning. The planning for logistics includes delivery of commodities (food, medicine, clothes, etc.), special rescue teams and rescue equipment, transfer of injured people to hospitals and mobilising medical professionals to support the people in need (Yi & Özdamar, 2007). It is also necessary to dispatch the necessary items on time, and to sustain the supply during the whole period that communities remain in the evacuation centres (Ozdamar & Yi, 2008). Due to inadequate or poor facilities available in the public shelters, some of the displaced prefer to move to paid private accommodation or a relative's house during the disaster periods (Lindell et al., 2011).

3.12 Mechanisms to Protect the Left Behind Property of People and Provide Security

People naturally tend to respond to emergencies based on their past experiences. The lack of trust in authorities and experts affects the perception of people and their willingness to evacuate in emergencies (Wachinger et al., 2013). Some communities in poverty may refuse to leave during a disaster evacuation due to concern about their limited assets being looted or destroyed (live stocks, tolls, machinery, etc.) or a perceived lack of livelihood support after an event (Eisenman et al., 2007). It is necessary to introduce alternative approaches to ensure the safety of belongings and assets of people, or to convince people enough that they can rebuild their lives or gain compensation (Mallick & Rahman, 2008). Pet ownership can also have a significant impact on an individual's decision to evacuate, and therefore it is necessary to make arrangements for people to move with their pets or to move pets to a safer place after household evacuation (Heath et al., 2001).

4 Methodology

For the overall study on which this paper is based, Sri Lanka and Indonesia were selected as the two case study countries. The two countries have similarities in terms of their 2004 IOT experience. Indonesia was the worst affected country from the 2004 IOT, and it was also subject to several tsunamis after the 2004 incident (NOAA, 2019a, 2019b). Sri Lanka was also severely affected by 2004 IOT, recording the highest number of deaths in Sri Lanka resulting from a natural disaster in recent history (Jayasuriya et al., 2006). However, unlike Indonesia, Sri Lanka did not face a tsunami after 2004 making it a good case to draw different experiences against Indonesia. The way the TEWMS operate in two countries are also different, as the

Indonesian system takes a more decentralised approach than the Sri Lankan one. Sri Lanka's warning decisions and evacuation orders are given at national level, where as in Indonesia the task of giving evacuation orders are spread across national and local levels (Haigh et al., 2020; Rahayu et al., 2019). Thus, the two cases provide very strong grounds for draw similarities and differences in TEWMSs. In this paper, the findings from the downstream analysis of the Sri Lankan case are reported.

Based on the conceptual framework presented in literature review (Sects. 3.1–3.12), data collection tools were developed to be used in the case of Sri Lanka. The three key data collection methods were semi structured key informant interviews (KII), focus group discussion (FGD) and observations (Obs).

After the establishment of TEWMS in Sri Lanka, legislations were enacted in the parliament in order to allow the establishment and functioning of Disaster Management organisations at the national and local levels. The national disaster management centre (hereafter referred to as DMC) and the Ministry of Disaster Management enable the operationalisation of Indian Ocean tsunami early warning and mitigation system (IOTWMS) in the country. The local disaster management centres (hereafter referred to as local DMCs) were established at the district level to implement the national level policies in their respective districts. The district DMCs act as critical sub-national level focal points to link the national level and the community within the IOTWMS. In addition, the operationalisation of the IOTWMS requires a wide range of institutions and functionaries in different fields. Therefore, any assessment of the system requires a systematic investigation of legal, organisational, technical, human and socio-cultural factors that underpin the functioning of the system. Table 1 is a summary of the scope of the downstream field investigation in terms of the institutional coverage and the geographical areas.

Given the complex and inter-connected nature of the system, a qualitative approach was deemed to be the best and the most appropriate for the study. The research design involved a range of qualitative data collection techniques such as FGDs, key informant interviews, face to face in-depth interviews, stakeholder consultations, field observations and documentary analysis. Table 1 also provides an overview of the qualitative data collection process involved in the investigation. The field study covered five out of the seven coastal districts affected by the 2004 IOT in Sri Lanka. The investigation also covered all the relevant institutional settings ranging from the district to the grass-roots communities in the areas covered. The data collection process has covered all the focal points in the downstream component of the early warning and mitigation system. Public consultations conducted in the five districts generated data on the experiences of the grass-root communities and vulnerable segments of society. Key informant interviews and the perusal of documentary evidence provided the basis for the analysis of the functioning TEWMS with respect to the twelve measures introduced in the conceptual framework (Sects. 3.1–3.12).

According to (Braun & Clarke, 2006), thematic analysis is "identifying, analysing and reporting patterns within the data". This method is widely used in qualitative research and could also be used to explain the phenomena evident during the data collection process, that can occur outside the defined themes (Boyatzis, 1998; Roulston, 2001). Hence, thematic analysis is chosen as the most appropriate method for

Table 1 Coverage of the downstream areas of the TEWMS in Sri Lanka

Target group	Tool	District					Number of Interviews
		Baticaloa	Ampara	Hambantota	Matara	Kalurtara	
Community consultations	FGD	01	01	01	01	01	05
District DMC	KII	01	01	01	01	01	05
District secretary office	KII	01	01	01	01	01	05
Divisional secretary office	KII	03	03	03	03	03	15
Police stations	KII	03	03	03	03	03	15
Schools	KII	03	03	03	03	03	15
Tsunami towers	Obs	02	02	02	02	02	10
Fishing harbours	KII	02	02	02	02	02	10
Grama niladaris	KII	04	04	04	04	04	20
Total interviews		20	20	20	20	20	100

Key FGDs focus group discussions, *KII* key informant interviews, *Obs* observations

analysing data for this study. The primary data is mapped against themes that were already identified during the literature review (Sects. 3.1–3.12), as are the strengths, issues, gaps and opportunities for improvement.

After analysis of the data, an initial set of recommendations was developed, and a draft integrated SOP document was prepared in collaboration with policy makers and practitioners in Sri Lanka. The integrated SOPs were tested for the first time during the region-wide Indian Ocean Wave exercise (IOWave) in 2018, and further feedback was provided for its further improvement. (Haigh & Amaratunga, 2018).The results of the data analysis, improved SOPs and recommendations derived from the study were presented at an FGD held in Sri Lanka in July 2019 (Amaratunga et al., 2019). The FGD involved experts in the disaster management field, government representatives, key stakeholders and the managerial level officers in the tsunami warning chain in Sri Lanka. The results were presented under each theme of the conceptual framework (Sects. 3.1–3.12) allowing the participants to ask questions and engage in discussions about each aspect. The findings of the study were validated during this FGD, and further improvements were made to the final recommendations.

5 Key Findings and Gaps; Analysed According to Conceptual Framework

It was important to define the downstream process of Sri Lanka's TEWMS at the outset of the study. The diagram presented in Fig. 1 explains the specific area dealt within the downstream of Sri Lanka's TEWMS, as well as the corresponding actors involved in the main stages of the process. As defined in Sect. 2, the downstream process starts when the official order of evacuation is given, goes through the processes of publicising and disseminating warning and evacuation information, evacuation of the communities, and ends when people return to the safety of their homes or when the tsunami threat is completely removed. When an earthquake is detected, the regional TSP informs the national tsunami warning organisations of the upcoming tsunami threat (IOC/UNESCO, 2015a). For Sri Lanka, regional information is provided by the Indian ocean tsunami early warning centre and received at the country level by the Department of Meteorology (DoM), which acts as the NTWC (documentary analysis). DoM also receives information from and maintains contacts with United States Geological Survey (USGS), California Integrated Seismic Network (CISN), Geological Survey and Mining Burau (GSMB) in Sri Lanka and Regional Integrated Multi-Hazard Early Warning System for Africa and Asia (RIMES). After confirming the tsunami threat, DoM passes the information to the DMC, who then issue the official order of evacuation (KIIs). This is the starting point of downstream for Sri Lanka's TEWMS. DMC publicise the warning information and evacuation orders through the media, local governments and district level DMCs. According to the key informants, the public will start the evacuation activities as soon as the warning information is given through national television and radio networks. However, in order to ensure that all the affected communities receive the

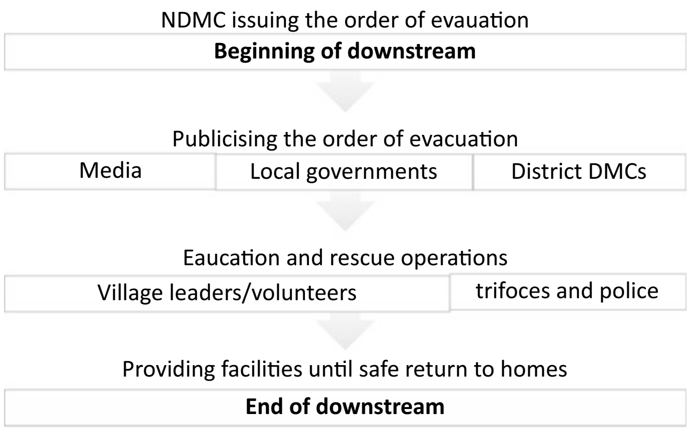

Fig. 1 Downstream of end-to-end TEWMS in Sri Lanka. Authors' composition

information and have access to evacuation routes and centres, the evacuation activities continue at the community level involving village leaders, volunteers, military forces and police. The rescue mission will also be conducted at this point to help those with limited mobility or trapped in areas with limited transport facilities (KIIs). The downstream process should ideally continue with provision of accommodation, food and medicine for evacuated people, until the tsunami threat has disappeared, and people can return to their homes (FGD).

5.1 Decision Making Mechanism

While main decisions regarding warning the public and ordering evacuation take place at the interface, the downstream decisions are mostly regarding information dissemination and ensuring safety of the public. This often involves the prompt and flexible decisions by the district and village level actors, as well as by media and security forces. In Sri Lanka, these decisions include sending the warning to rural or distant communities outside the normal communication system, assisting pregnant women, disabled, sick and elderly people to move quickly to a safer place, assisting the organisations that deal with vulnerable communities such as hospitals and care homes, ensuring the safety of property left behind, providing adequate space and facilities at the evacuation centres, and ensuring the health and safety of evacuated people. Dissemination of the messages from the national focal point down to district and lower levels, including the community, is streamlined through multiple channels. This includes, for example, the DMC, public administration, tsunami towers, security services, media, specialised agencies, media, village DM committees and civil society organisations. Rather than looking at documented standards, decision makers at lower levels tend to take practical decisions based on local circumstances, and very likely based on people's needs. However, the local actors have to adopt a number of different roles and responsibilities in an emergency, due to the limited availability of resources. On the other hand, the village level disaster management committees are not functioning effectively in all parts of the country. There is a lack of documentation and understanding about the level of authority and influence of local level actors to take decisions.

5.2 Clearly Defined Actors

The roles and responsibilities of key actors across the vertical and horizontal divisions are well defined within the TEWMS in Sri Lanka. As mentioned previously, a wide variety of actors, from district DMCs to village level committees, are engaged in the downstream of the TEWMS. Figure 2, detailing the actors in the TEWMS and their positions within the institutional structure, was created using the information from key informant interviews. However, the local government institutions, in both rural

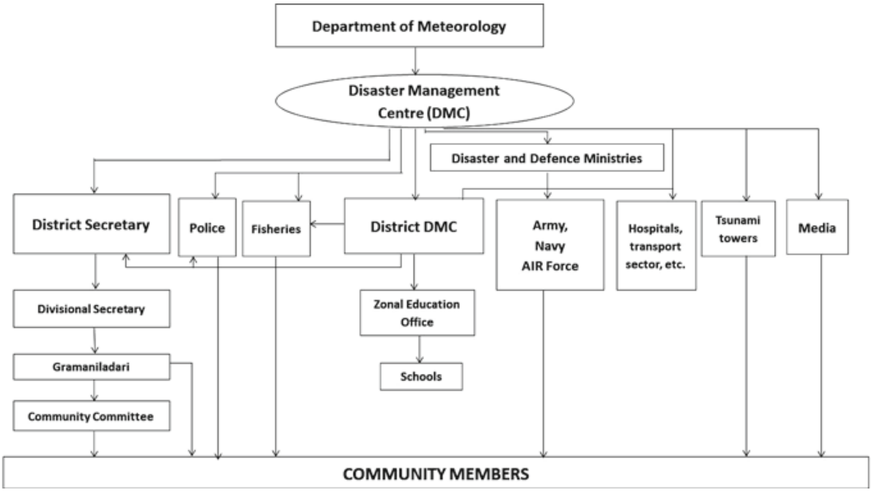

Fig. 2 Tsunami early warning system: downstream implementation structure. Authors' composition

and urban areas, are not assigned clear roles within this structure. At the same time, the tourist sector agencies are also not properly integrated, which may cause delayed or absent warning communication to local and international tourists.

5.3 *Standardisation*

In Sri Lanka there is an established set of SOPs that are applicable to DMC personnel, but these are not available for other functionaries. Most other actors have been sensitised to follow key steps through training, circulars and orientation programs, but given the vital roles of these other actors, the lack of multi-agency SOPs is a gap that can undermine the transmission process, both horizontally and vertically. For instance, at the community level, Grama Niladari (GN) is a key actor whose role and responsibility can be more clearly defined by way of an SOP. If the GN has a registry of exposed households and individuals, it can be checked against the evacuated number of people. At the same time, GN also has the capacity to identify a list of people with limited mobility, so that when the warnings are issued, their rescue operations can be prioritised using local volunteers. GN also do not have a clear guideline on contacting the military or police in case of assistance for rescue operations. Such capacities at village level are missed opportunities when the village level SOPs are not defined within the system. More broadly, one of the major issues that emerged was the absence of an integrated set of SOPs for all the stakeholders in Sri Lanka's TEWMS. After this issue became apparent during the study, an integrated SOP was developed as a study outcome and was tested during the IOWave 2018 exercise (Haigh & Amaratunga, 2018). The integrated SOPs broadly reflects the key actors and interactions, as well as detailed linkages to intra-agency activities and SOPs. The local level SOPs were also introduced through the study. However, only national level SOPs were tested during the IOWave 2018 exercise, again missing an opportunity to formally integrate local SOPs within the practices that affect the whole TEWMS in Sri Lanka.

5.4 Technical Capacity

There are 77 tsunami towers located around the coastal belt of Sri Lanka, and 37 of them are in the area covered by this study. They are also under continuous monitoring and testing.

Most of the officials agree that there is adequate technical capacity in all institutions to warn people in an emergency. However, through the observations and interviews, it was discovered that the equipment might not be sufficient to cope with the requirements in the field in an actual emergency situation. During the interviews, it was also revealed that the department of fisheries face problems with technical capacity. Due to the weak and breaking signal, and poor technical facilities in many fishing boats, it is difficult to get the warning messages across to fishermen. This was found to be especially so in one-day boats that operate in the shallow seas. Their radio communication systems are either insufficient or non-existent.

5.5 Human Capacity

In most instances the human capacity, from district to village level, was found to be at a satisfactory level to deal with an emergency. In addition to the public sector employees assigned to disaster management roles, community members provide services in villages on a voluntary basis. However, it has been a challenge to maintain the functioning of these committees over the years due to members being preoccupied with other priorities such as work commitments and economic activities. Most rural men travel to and live in urban areas for employment. As a result, it is mostly female participants who engage in training and deliberation activities, while the participation of men and youth is minimal. At the GN level, tasks are assigned to several sub-committees, such as warning dissemination, evacuating vulnerable people, first-aid, shelter camp management and security of properties. Some gaps exist in terms of lack of training for the newly recruited people for these sub-committees. The effective functioning of the system also gets disturbed when trained or experienced functionaries are leaving their positions due to retirements or transfers. Therefore, there is a need to continuously monitor the issues of recruitment, replacement, training and deployment at the downstream level of the TEWMS.

5.6 Spatial and Socio-Cultural Issues

In Sri Lanka, the social, cultural 6and spatial factors influencing the early warning system can be significant, due to the diversity of communities who are potentially at risk. One of the positive influences is most Sri Lankan people are traditionally trained to be hospitable and look after each other. Schools, Buddhist temples and other religious places are widely used to accommodate evacuated people until the affected communities are able to return to their habitats or alternative places of residence are found. At the same time, the people who are not affected by the disaster offer their support to affected communities in terms of cooked food, clothes, medicines, sanitary products and dry rations. Media organisations, religious institutions, universities, as well as community based voluntary groups, act rapidly to mobilise the donations and distribute them to relevant communities.

Drills are taking place at the village level to train people to evacuate and take actions during a tsunami inundation. However, a tsunami did not occur after the 2004 event, and maintaining the vigilance of people has become a challenge. The frequent exposure to drills makes some people complacent about the possibility of an actual tsunami, and more innovative methods are needed to sustain community engagement and participation. As a country exposed to traditional beliefs and practices, some Sri Lankans also believe in religious and astrological predictions. There is a risk of people believing the non-factual messages form astrologers and soothsayers, rather than official warnings.

Although hazard maps are available at the national level, there are gaps in the availability of hazard and vulnerability maps at a local level. During the IOWave 2018 (validation) exercise, it was observed that some officers are not equipped with adequate knowledge to read the hazard maps and understand their content. There is also a need to review and update the existing maps, and to create new maps to reflect the changes in risk and vulnerability.

5.7 Vertical and Horizontal Coordination

The coordination among actors at different levels (vertical coordination) was found to be at a satisfactory level in the overall TEWMS in Sri Lanka. Most of the institutions in the downstream are well connected to the main information flow within the system. However, at lower levels, inter-institutional coordination (horizontal coordination) is often not smooth due to compartmentalisation of state and other institutions. For instance, schools are not well integrated into the system and therefore, often rely on their own administrative hierarchy at the local level. This is also true for tourist establishments as well as fishery sector functionaries. Some of the issues in the fisheries sector are technical, and these difficulties lead to a lack of coordination among the different actors.

5.8 Formal and Informal Communication

In Sri Lanka, people facing the risk of tsunami are most likely to receive the warning message and order for evacuation on time because the information is passed down through multiple mechanism in different modes. While the formal messages are passed through the official administrative hierarchy, the media is also sending the messages through their communication channels. Social media is also widely used to disseminate information, and tsunami sirens are activated to alert people for speedy evacuation. Nevertheless, rumours often travel through informal channels and these can mislead and confuse people who are exposed to tsunami risk. A national help line has been set up for people to contact and clarify information in such instances.

Communication gaps can be seen in sectors such as fishery and tourism, exposing some fishermen and tourists to danger. Communication in public administration, particularly from the DS downward, is not always reliable, particularly at night and during holidays. Some services in the public administration do not usually operate day and night, and throughout the year, making it difficult to pass down information through administrative channels.

During the IOWave 2018 exercise, the communication network was tested, including those at downstream level. According to the observation report (Haigh & Amaratunga, 2018), the bulk of downstream information dissemination was coordinated by the DMC. The activation of local evacuation processes is done by the district disaster management committees, and last mile communication is carried out using the early warning towers, megaphones, sirens and public announcement systems.

5.9 Ongoing Evaluation

Between district and community, the main forms of evaluation are an annual drill and the biennial, region wide IOWave exercise.

The drills take place at the national and the regional levels, but local government institutions and some communities also participate. Tsunami towers are also regularly checked for their smooth functioning. However, due to the lack of a recent tsunami event in Sri Lanka, people are losing interest in the drills and in recent years there has been poor participation. Engaging the communities and raising awareness remains a significant challenge.

Evaluation of the downstream process during the IOWave is minimal, as more focus is given to the national level operationalisation. This was further established through the observation that local level SOPs for community evacuation were not tested during the IOWave 2018 (validation) exercise. The downstream process was tested in terms of information dissemination by DMC and local disaster management committees, as well as through an evacuation drill, but that only took place in three districts.

5.10 Vulnerable Groups

Being a developing country, the transport systems and buildings in Sri Lanka are not very accessible. Most of the buildings do not have built-in emergency exit mechanisms. People with reduced mobility face difficulties in meeting their needs on a daily basis. This can be seen as a barrier to evacuate people with special needs in an emergency situation like a tsunami. However, disaster management committees are established at the village level, with a special focus on evacuating such vulnerable people. There are also arrangements to identify vulnerable people in a certain GN division in advance of a disaster situation and keep a record, so that they can be easily traced and supported in case of the disaster. However, those who are expected to help vulnerable groups do not always have the logistical equipment to carry out this responsibility. Tourists are also vulnerable if they do not receive the timely warning and guidance to find their way to safer places. Nevertheless, the personnel from security forces are available to provide some support in such cases.

5.11 Logistics for Evacuation

Widely available information about logistics is also a part of the drills. By participating in drills, people are educated about the evacuation paths, safer places to go and the places to avoid. The direction boards are set up to indicate which way to move and where to go. People have been instructed to keep their valuable things pre-packed so that they do not have to waste time to look for them. However, direction boards (sign boards) that were installed have frequently been damaged or vandalised so the people in some areas can no longer rely on them. In some areas, these signs are not properly maintained. Some tsunami evacuation paths are too narrow for large groups to move away from danger in an orderly fashion. In other cases, transport is necessary, but such facilities may not be available when needed. This will adversely affect vulnerable groups. Confusion about the evacuation procedures and a lack of local guidelines were some of the weaknesses that were also observed during the IOWave 2018 exercise. There is also a need to improve the availability of shelters and access to evacuation routes within the tested districts.

5.12 Mechanisms to Protect Properties of People

Although people generally respect orders for evacuation, some may resist due to a fear of any valuables left behind being robbed by looters. Some of the properties were vandalised during the 2004 tsunami and an inability of law enforcement agencies to provide adequate security has not helped to build the confidence of people in many areas. Special sub-committees are established at the GN level for security of properties of community members, consisting of community members, as well as pre-assigned army and police personnel from the area. However, in some areas there is no adequate information to confirm the smooth functioning of these sub-committees, due to members being absent from training activities and also due to an insufficient number of officials. A few local government workers and security personnel are assigned a large number of tasks and those, in face of an actual tsunami, would be insufficient to attend to all the different responsibilities.

6 Conclusions, Recommendations and Future Research

The overall tsunami early warning system—at a national, sub-national and local level—is functioning in many respects. However, some gaps were evident in the downstream part of the system in Sri Lanka. There is a lack of synergy between the SOPs, inadequate technical and human resources, weak linkages to village level DM committees, a lack of integration of fishery and tourism sectors to the warning mechanism, and public complacency towards drills. Nevertheless, it is possible to improve functioning of the downstream process in Sri Lanka by introducing certain proactive measures. The following recommendations were identified jointly with the local stakeholders following the presentation of findings in a FGD.

- Community level DM committees need revamping to make them more effective. This may include offering incentives like official recognition and opportunities to get involved in other government programs to participate at a community level.
- Strengthen the link between DS and lower tiers of administration by establishing SOPs and providing better communication facilities like telephone hotlines. There is also a need to develop SOPs for many downstream actors.
- Strengthen communication channels between fishermen at sea and managers of fisheries harbours.
- Issue information leaflets in other relevant languages to tourists so that they are well informed to act in the case of a tsunami.
- Encourage tourist establishments and local councils to develop alternative evacuation sites near settlements and tourist hotels, such as well landscaped tsunami mounds that can be used for multiple purposes when not used as for evacuation purposes.
- Where key actors currently do not have adequate equipment to perform their functions relating to tsunami early warning, such facilities should be provided following a needs' assessment.
- Adequate training to newly recruited functionaries and refresher training to long serving officers needs to be provided on a regular and sustained basis.
- Develop and implement a motivational program to encourage community members to take part in periodic drills.

- Additional media programming through mainstream media to create awareness and dispel myths by disseminating factual and scientific information among the general public.
- Introduce a periodic evaluating and monitoring system to ensure the momentum in the functioning of the TEWMS system with a focus of on key actors and institutions.
- Strengthen the evacuation procedure by improving on evacuation infrastructure such as direction boards, evacuation paths, shelters, logistical facilities, and provision of adequate space.

The above recommendations were presented to the relevant actors in Sri Lanka so that they could be implemented as a part of future work. There is potential for extending the research on downstream operation of the TEWMS to other countries affected by tsunamis. The above conceptual framework can also be improved and adapted to analyse other types of disasters, such as in a multi-hazard environment.

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A Study on Stakeholder Trust in Sri Lanka's Multi-Hazard Early Warning (MHEW) Mechanism

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Abstract Focusing on human behavioral aspects are significant in the effective delivery of Early Warnings to the community on time. In that context, the extent of trust towards the Multi-Hazard Early Warning mechanism plays a major role. This deals with delivering the warning messages related to several hazard categories and the cascading disaster risks triggered by one hazard striking. Among the stakeholders who are interlinked with this mechanism, first responders play a vital role in disseminating the Early Warnings to the vulnerable community at downstream level. To examine the perception of the first responders, a survey was undertaken and overall 1004 responses were collected. From the indicator calculation of the trust based on the mean score and the sentiment score, the extent of the perception level was determined. This denoted that there exists a lower level perception of trust towards the existing Multi-Hazard Early Warning mechanism. This was revealed with this basis of the content of the message, level of understandability of the message and extent of variation of the immediate response with time towards the warnings delivered on different hazard categories. Further, the correlation determination of experience of the first responders with the number of people with non-varying trust levels was examined through IBM SPSS software. Here, the graphical representation denotes a negative polynomial relationship with r^2 value of 0.9. This denoted a strong negative correlation among the two parameters, in which the experience of the first responders was limited to a maximum of 5 years. These results were then compared with the findings of the recent research study that was on community-level assessment of the perception on the existing Multi-Hazard Early Warning mechanism. From the results obtained, it was revealed that the community has a high preference on adapting to Early Warnings delivered through mobile phone while first responders have a lower level of trust on this mechanism.

Keywords Trust · Stakeholders · Community · First responders · Multi-hazard early warning (MHEW)

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1 Introduction

Trust is considered an important parameter that determines the human level perception towards the system's functional behavior (Carlos Roca et al., 2009). It is recognized that due to the featuring behaviors in the considered system, the human level perception patterns concerned with trust levels can be varied (Macrae, 2014). This was highlighted with the concern on the features of the Early Warning (EW) alert delivered to the community during emergency disaster situations. Poor level of understandability, weakness of on-time delivery of the warnings and completely missing the warnings delivered were identified as some of the key influencing facts over the deterioration of the trust level of the community (Bruce et al., 2011). Based on the experience of the information delivered through the EW, the trust level of the society is determined to be more dependable (White & Fu, 2012).

The recent incident of Fani cyclone in Odisha region in India could be considered as a major example where the highest level of preparedness was achieved (Dhaka Tribune, 2019). Here the trust among the community could be seen at the highest level towards the existing EW mechanism where the message was delivered within a short time period and mass evacuation was conducted with nearly 1.8 million community evacuation towards safer locations (Kumar et al., 2019).

The EW mechanism is defined as an integrated system of hazard monitoring and forecasting, risk knowledge, communication and dissemination activities and response capabilities which enables to take timely decisions and actions to reduce the disaster risks (Sufri et al., 2020), (UNDRR, 2019). With this concept, the Multi-Hazard Early Warning (MHEW) is defined to address several hazards and the impacts which are induced alone and cascading from hazardous events. It was identified from the recent research studies that the stakeholder level engagement in the main four elements of this MHEW mechanism which are risk knowledge, monitoring and forecasting, warning dissemination and communication and preparedness and response capabilities, is considered inadequate in most of the countries (Aguirre-Ayerbe et al., 2020). Further, it was revealed from the past disaster incidents that the poor integration among the stakeholders and poor assigning of the roles and responsibilities among the stakeholders was a major factor for the poor dissemination of the EWs to the community.

In the Sri Lankan context, the MHEW mechanism is initiated with the focus of addressing critical natural hazard categories such as floods, landslides, heavy winds, droughts and tsunami (DMC, 2016). The dissemination mechanism of MHEW in Sri Lanka has outlined towards reaching to grassroot level of national, district, divisional and grama niladari authorities from the technical level authorities (Jayasiri et al., 2018). Further, the influence of external and internal stakeholders in undertaking the tasks related with MHEW mechanism in Sri Lanka was identied in the recent research studies (Rathnayake et al., 2020), (Perera et al., 2020). Here the key decision making authority of MHEW dissemination is followed by the Disaster Management Authority (DMC) in Sri Lanka (DMC, 2016). Under this coordination by the DMC, the tasks related with risk knowledge, monitoring and forecasting, warning dissemination and communication and preparedness and response capabilities in the MHEW mechanism are undertaken.

Among the stakeholders linked with MHEW mechanism in Sri Lanka, the first responders are most significant (DMC, 2016). The role of first responders was clearly defined in the Federal Emergency Management Agency (FEMA) National guidelines, where the responsibilities and the actions needed to be taken in the disaster situations (Fugate, 2014). The first responders are mainly recognized as the persons who are in the authority at the ground level like police officers, Grama Niladari and the administrative officers in different sectors like doctors and teachers who need to be the first level communicated before the warnings delivered to the public (Samarajiva & Waidyanatha, 2009). It is defined that the key concerning the perception level of these stakeholder categories like first responders needs to be examined in the investigation of the effectiveness of the existing MHEW mechanism (Shehara et al., 2019). The poor integration among the stakeholder categories and lack of defined roles and responsibilities were identified as the key driving factors for this (Jayasiri et al., 2018; Perera et al., 2020; Rathnayake et al., 2020; Shehara et al., 2020a, 2020b, 2020c).

Accordingly, under this study, the focus is on the identification of the extent of stakeholder perception towards the existing MHEW mechanism in the Sri Lankan context. Under this, the community and the first responders perception evaluation is undertaken with the concern selected key features in the MHEW mechanism. This mainly focuses on the communication and dissemination of the EW alerts considering several hazards and the disaster risks which trigger the cascading effects.

2 Literature Review

2.1 Overview of MHEW Mechanism

Multi-Hazard Early Warning Mechanism is mainly developed with four of the main pillars defined as risk knowledge, monitoring and forecasting, warning dissemination and communication and preparedness and response capabilities (UNDRR, 2019). Based on these considered four pillars, the effective delivery of the warning dissemination and safe evacuation of the community is performed. This mainly focuses on enhancing the preparedness and enacting timely actions towards several hazards and disaster risks which are triggered by cascading from the major hazards.

The main elements of the MHEW mechanism were defined as upstream, interface and downstream based on the flow pattern of the information related to the hazard information (Lendholt & Hammitzsch, 2012). As defined here, the main tasks related to these key elements are denoted in Table 1.

Table 1 Key elements of MHEW mechanism

Upstream	Physical phenomenon
	Sensor constellation
	Sensor event series
	Situational picturizing
	Disaster monitoring
Interface	Decision making
Downstream	Warning dissemination
	Information logistics
	Warning and alerting
	Distribution through channels
	Message reception

In the effective performance of the MHEW mechanism in the emergency disaster situations, the parameters which mainly lead are more broadly elaborated as shown below (Twigg, 2003).

- A lead time of the warning delivering
- The accuracy level of the warning messages
- Delivery of probabilistic forecasts
- Communication and dissemination strategy of Early Warnings
- Usage of new techniques to alert the communities
- Level of understandability of the warnings
- The undertaking of the warning delivery to relevant and specific users.

The poor performance of these featuring parameters is considered more influential towards the featuring concerns such as deterioration of human perception levels among the stakeholders interlinked with the MHEW mechanism.

2.2 Impact of Stakeholder Categories (Community Level and First Responders)

The principal stakeholders who are engaged with the disaster management authorities at the national, provincial and local levels and community level are highly responsible for the dissemination of the MHEWs (World Meteorological Organization, 2018). In the mechanism of dissemination of the effective MHEW mechanism towards the downstream level communities, the integrated responsibility delivering by each of the stakeholder parties are considered significant. The alerts and threats issued from the technical authorities who detect the warning possibilities from extreme emergency situations are delivered mainly to the vulnerable communities through these stakeholder categories. With this, the mitigation of the damaged content and the safe evacuation of the communities to safer locations are managed in timely behaviours. The community groups are significant in directing the vulnerable communities through safe evacuation paths and managing extreme disaster situations before such disasters strike (Shehara et al., 2020a, 2020b, 2020c). As the MHEW mechanism not only comprise of undertaking the communication and dissemination tasks, but also the risk knowledge, monitoring and forecasting and tasks related to preparedness and response capabilities, it is essential to coordinate with each of the stakeholder categories (Lendholt & Hammitzsch, 2012).

Target 7 of Sendai Framework for Disaster Risk Reduction (2015–2030) emphasizes, the necessity to increase the availability and accessibility of MHEW mechanisms and disaster risk information (Saja et al., 2020). To achieve this, it is required to strengthen the collective responsibilities among the stakeholder parties who are interlinked with the MHEW mechanism (AL-Fazari and Kasim, 2019). The main categories of these stakeholders with their responsibilities related to the MHEW mechanism with respect to the Sri Lankan context are represented in Table 2 (Jayasiri et al., 2018; Perera et al., 2020).

Among the stakeholders who are interlinked with the MHEW mechanism in Sri Lanka, the community sector and the First Responders play a major contribution towards the effective delivery of the alerts in the downstream level (Rathnayake et al., 2020). In the downstream level of the MHEW dissemination, the community level is mainly reached through the alerts delivered through first responders (Chen et al., 2019). The warnings delivered through the technical agencies delivered through

Table 2 Key stakeholders and their responsibilities

Stakeholder category	Responsibilities
Community	Need to actively involved in the operational performance of the EW mechanism in emergency disaster situations
Local government	Development policies and framework integrated with reducing the disaster risk through effective EW mechanism
Regional institutions and organizations	Facilitation of effective EW strategies among the local level community with integration of national plans
Non-governmental organizations	Mainly involved with awareness and providing aids and support mechanism in EW mechanism implementation
International organizations	International level support and coordination in national early warning activities
Private sector organizations	Development of EW mechanisms integrated with new technologies
First responders	Dissemination of the EW alert to the people underneath the power of the person
The scientific and academic community	Need to develop the risk management strategies adoption of new techniques with the minimization of disaster impact

the decision making authorities and the alerts are issued towards the first responders to reach the community level (Bui, 2018). This way, the safe evacuation of the community and the minimal damage to the physical infrastructure are expected to be at a secured level. The focus here is mainly directed towards the main stakeholders of the downstream level of the MHEW mechanism, who are the first responders and the community level. These are mainly focused to identify the gaps in the existing MHEW mechanism which was elaborated from the recent disaster incidents.

Stakeholder behaviors in the MHEW mechanism are significant in the effective delivery of the EWs and safe evacuation of the vulnerable community towards natural hazards. This importance of the behavior of the stakeholders in each phase of the MHEW mechanism was examined with the consideration of case study examples in the Sri Lankan context (Fonseka et al., 2020). Based on this study, the idealized conceptual model which is generalized for the disaster categories is represented in Fig. 1 (Fonseka et al., 2020).

With the identification of the stakeholder behaviors, defined key responsibilities and the response deliveries are needed to be performed at relevant phases in the Disaster Management cycle. Here the activity space is defined based on the number of activities that are responsible just before, during and just after the disaster occurrences.

Among these stakeholders who are mainly interlinked with the MHEW mechanism, the first responders are considered more significant in the dissemination of the MHEW messages at the downstream level. They are mostly the first on the emergency scene and are a critical part of getting the community the safety they need when disaster strikes (Public Health Emergency, 2018). The alerts and warnings issued through the technical agencies are disseminated through Disaster Management authorities towards these first responders, which they are acting as an interface between DMC and community (Chen et al., 2019). As defined previously, these are

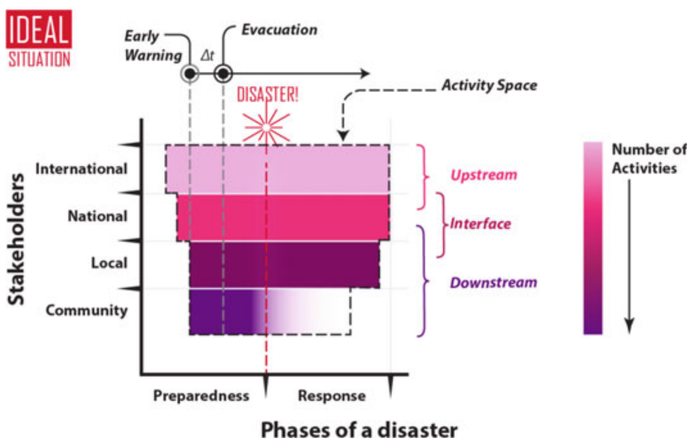

Fig. 1 Stakeholder behavior related with disaster management cycle

the first to respond in emergency disaster situations. They have the immediate responsibility towards making aware of the community at the local district and regional levels (Buzzelli et al., 2014). This is delivered with the target of safely evacuating the community and minimize the impacts triggering from the extreme disaster situations. Starting from before the disaster strikes, the first responders initiate their responsibilities towards managing the immediate response activities. In the Sri Lankan mechanism, these first responders are recognized as the special category of stakeholders who are engaged in real life scenarios as police officers, teachers, grama niladaris, administrative officers relate to the disaster management authorities.

It is recognized that the main responsibilities which are interlinked with the first responders in the dissemination process of the MHEW mechanism are considered more significant. The alerts and the warnings which are issued through the decision making bodies as passed by the technical agencies are disseminated to the community target groups mainly through the first responders (Buzzelli et al., 2014). As defined in the policy frameworks, the communication and dissemination of MHEW alerts is delivered based on the following flow in Fig. 2 (Momani & Alzaghal, 2009).

Accordingly, the key role played by the first responders who are engaged in different sector roles in the professional environment, but responsible for timely and accurate delivery of the EW alerts towards the vulnerable community with minimum lead time are considered highly significant (Girons Lopez et al., 2017; Waidyanatha, 2010). In response to an emergency disaster situation, it is required to dynamically form the teams and require to incorporate effective communication mechanisms during and after such disasters (Chen et al., 2019).

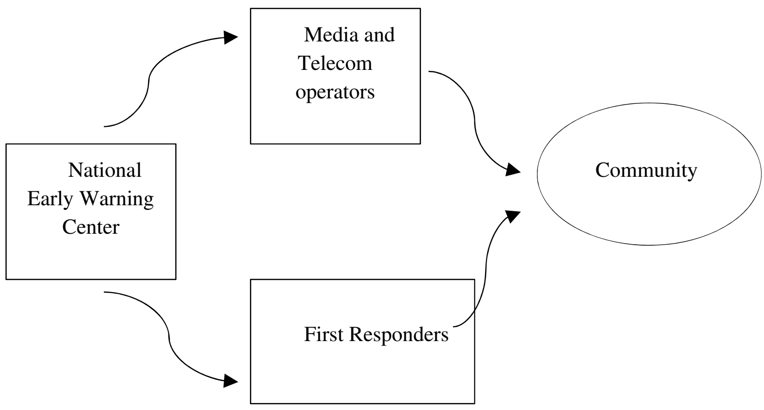

Fig. 2 Flow of EW information

2.3 Importance of the Stakeholder Level Trust on MHEW Mechanism

The importance of the stakeholder involvement in the MHEW in the Sri Lankan context was examined for the identification of key stakeholders who are interlinked with the MHEW mechanism (Shehara et al., 2019). Based on the critical hazard categories which are floods, landslides, tsunami, high winds and droughts, the stakeholder behavior related to the MHEW mechanism was examined with the application of the Social Network Analysis (SNA) approach. As per the findings of this research study, the necessity to integrate the stakeholder groups in the effective dissemination of the MHEWs was majorly revealed. In the existing mechanism, the poor identification of the roles and responsibilities by each stakeholder level has led to the massive destruction which has occurred upon human lives and the infrastructure sectors. As to minimize these impacts, the necessity to focus on the extent of the trust level among these stakeholders emerged.

It was further revealed from the research studies that, based on the extent of trust level developed among the stakeholders, the variation of the immediate response actions towards the EWs undertake (Drabek, 1999). Further, the importance of the communication mechanism which is related to the MHEW was mainly highlighted with the featuring concern on the trust level based on the communication mode of alert delivering to communities and the stakeholders (Steelman et al., 2015; Shehara et al., 2020a, 2020b, 2020c). Further, the trust behaviors have mainly involved dealing with the corporate strategic behaviors to make more effective on the stakeholder responses (Gray et al., 2012).

Based on the behaviors of trust, it has revealed that the perseverance of a party towards system behavior is mainly related to trust level variation (Kalkman & de Waard, 2017; Shehara et al., 2020a, 2020b, 2020c). Here the key features related to the effective MHEW mechanism are sorted based on the review of the literature. It has denoted that the EWs delivered based on the emergency disaster situations are needed to be specific and to a defined scope level (Lendholt & Hammitzsch, 2012). Further, these need to be highly biased along with the specific features such as the authority of issuing the alerts, the scope of the alert, complexity of the alert, level of understandability of the alert and the language of the alert (Ahsan et al., 2020; Lendholt & Hammitzsch, 2012; Macrae, 2014).

From the above-identified key features from the literature, the following parameters were selected in assessing the extent of perception from the stakeholders. These were chosen based on the examination of the trust behaviors related to the EW message delivered through the MHEW mechanism as an alert (Macrae, 2014).

- Content of the message
- Level of understandability of the message
- Variation of the response with time.

Based on the extent of the trust on MHEWs, the reaction being taken for the safe evacuation tends to vary with time (Ahsan et al., 2020; Lendholt & Hammitzsch, 2012; Macrae, 2014). Further, the variation of the content of the MHEWs delivered through different modes of communication is another depending factor towards the trust level variation (Shehara et al., 2020a, 2020b, 2020c). With the extent of awareness on different hazard categories and the severity of the MHEWs issued, the variation of the trust level tends to happen with time (Shehara et al., 2020a, 2020b, 2020c). Accordingly, these key features are more broadly examined in further sections to examine the extent of trust levels.

2.4 Methods of Evaluating Trust Behaviors

In examining the trust behaviors of the stakeholders, different research techniques and decision-making models have been developed. For example, in the evaluation of the perceptional behavior of the first responders related to the fire hazards, the study used indicator calculation based on the mean score and the sentiment score. Further, the application of the fuzzy logic approach in the decision making aspects related to the parameters like trust behaviors of the community was performed in many of the research studies. A summary of some of these key approaches identified through literature is summarized in Table 3.

From the above defined research approaches, the indicator calculation approach was considered in this research study to evaluate the perception of trust level on MHEWs. This was mainly used to quantitatively determine the community perception level with the focus of the social parameters (Arru et al., 2016). The main two indicators selected here are mean score and sentimental score which were considered in the perception calculations done in similar research studies. An overview of these indicator calculations is presented in Table 4.

Table 3 Research techniques

Research approach	References
Fuzzy set theory, fuzzy cognitive maps	Feng et al. (2011), Aref and Tran (2015), Wei et al. (2008)
Analytical network process	Nilashi et al. (2015)
Indicator calculation	Arru et al. (2016)
Conceptual modeling	Aulakh et al. (1996)
Bases and a Foci approach	Yang and Mossholder (2010)

Table 4 Indicator overview

Indicators	Definition	References
Mean score	The score based on the arithmetic mean of a set of responses	Potts and Phelan (1996), Roitman et al. (2017), Hardouin et al. (2011)
Sentiment score	The score calculation based on the positive responses in proportion to the negative responses	Singh and Paul (2015), Dey et al. (2018), Thet et al. (2009)

3 Data Collection

3.1 Questionnaire Survey

A questionnaire survey was carried out in order to identify the perception of first responders on the existing MHEW mechanism in Sri Lanka. The following key parameters which are denoted in Table 5 were measured from this survey. These were mainly considered in the determination of the first responder's perception of the trust level of the first responders towards the existing MHEW mechanism. The featuring perspectives of the EW message were obtained to examine the perception level of the existing mechanism.

3.2 Sample Selection

In selecting the sample for the conducting of the telephone interviews, different sampling techniques were examined and systematic random sampling was chosen as the preferred method. Based on the systematic random sampling, a sample size of 2000 was selected to conduct the survey. When compared with other sampling techniques, systematic random sampling is considered to be statistically efficient (Bellhouse, 2014). The determination for the sample selection was conducted based on the following defined theoretical basis shown in Eq. (1) (Levy and Lemeshow, 2013).

$$\text{Sampling fraction} = \frac{n}{N} \tag{1}$$

Here n = selected sample size (n = 2000).

Table 5 Main defined questions of the questionnaire

Q1	Variation of the action taken after receiving the EW message
Q2	Level of understandability of the message
Q3	Content of the message

N = Population size (N = 23,123).

Accordingly, the 1/11 was obtained as the result of the sampling fraction which represents the selection of the 11th parameter in the overall population for the selection of the sample of first responders.

3.3 Method of Data Collection

The data collection was mainly undertaken to identify the responses from the first responders. This was mainly conducted through the telephone interviewing approach, as it was revealed that the simplest and most convenient approach to collect such a number of responses from the chosen sample size was telephone interviewing (Sweet, 2002). The diverse distribution of the first responders in each of the districts in the country could be easily reached through this telephone interviewing approach of data collection. From the selected sample of 2000 responders, data collection was limited to 1004 responses based on the challenges that had to encounter.

The textual data was collected based on the questionnaire survey developed in the examination of the perception of the responders. This way, the qualitative data collection was conducted among the selected sample category of the first responders. In conducting this approach, challenges could be faced with limited time availability of the responders, reaching the responders amidst the busy schedules and thoroughly validate the identity of the person conducting the survey. These need to be highly concerned in dealing with qualitative data collection approaches.

3.4 Demographic Information

The general overview of the demographic features of the responders obtained from the responders is discussed here. Based on the gender variation, 62% of the responders were related to the male category and the remaining 38% of the responders were related to the female category. Further, based on the age category distribution of the responders, the responder category represented 1% of below 25 age category, 36% of age category 26–45 years, 46% of 45–60 years, 6% of above 60 years and 11% were reluctant to express the age categories. The experience as the first responders were examined with the results obtained as 54% of one year experience, 25% of two years, 12% of three years, 4% of four years and 5% of five years. Accordingly, the further indicator analysis proceeded with the mean score generation based on the age category distribution and the gender category distribution of the responders.

4 Data Analysis

From the overall 1004 sample size, 457 responders were responded to say that they are aware of receiving the messages and they are identified as the first responders related to the MHEW mechanism in Sri Lanka. First, the reliability of the obtained data collection of the responses was conducted through the determination of the Cronbach alpha value for the determination of internal consistency. From the results obtained, it was considered for further analysis based on the determination of indicators to determine the trust level perception of the first responders. This was mainly conducted from the determination of the mean score and the sentiment score values. Further, the responses obtained proceeded to the determination of the coefficient of determination to find the correlation among the variation of a number of people whose trust level does not variate with the increasing of the experienced years as first responders. These are more broadly discussed in the below sections.

4.1 Reliability Analysis

In order to examine the suitability of the collected data for further analysis, reliability analysis was conducted through the determination of the Cronbach alpha value. From the examination of the Cronbach alpha value, the internal consistency determination of the Likert scale responses could be obtained (Taber, 2018). The definition of the deriving of this Cronbach alpha is denoted Eq. (2).

$$\propto \; = \frac{N\,\bar{c}}{\bar{v} + (N-1)\bar{c}} \tag{2}$$

$\propto$ = Cronbach alpha.
N = Number of items.
$\bar{c}$ = Average covariance between item pairs.
$\bar{v}$ = Average variance.
The obtained Cronbach alpha value obtained based on the IBM SPSS software is 0.764 which was considered more reliable with the considered basis of 0.7 marginal value (Stephanie, 2014).

4.2 Indicator Calculation

The perception of the trust of the first responders towards the MHEW mechanism was mainly determined through the calculation of the mean score and the sentimental score indicators. The definitions as specified for the mean score and the sentimental score are defined as below.

- Mean score

The mean score is defined as the arithmetic average calculated with the set of defined variables (Lember et al., 2012). The representation under the calculation of perception mean score is denoted Eq. (3).

$$\mathrm{f_m}(\mathrm{r}_{11},\ \mathrm{r}_{12,}, \ldots, \mathrm{r}_{3\mathrm{n}}) = \frac{g_m(1),\ g_m(2),\ g_m(3)}{3} \tag{3}$$

where,

$$\mathrm{g_m}(\mathrm{i}) = \frac{(r_{i1} + r_{i2} + r_{i3})}{3}.$$

- Sentiment score

The defined score determination of the sentiment score related to the economic concern determination was denoted as Eq. (4) (Gaski & Etzel, 1986). Here the sentiment values on the decision-making process are considered as neutral with the theoretical definition of the parameter (Ludvigson, 2004).

$$\mathrm{f_s}(\mathrm{r}_{11},\ \mathrm{r}_{12,}, \ldots, \mathrm{r}_{3\mathrm{n}}) = \frac{g_s(1),\ g_s(2),\ g_s(3)}{3} \tag{4}$$

where,

$$g_s(i) = \frac{pos(i)}{pos(i) + neg(i)}.$$

Investigation of the perception of the community towards the EW mechanism related to fire safety was concerned with the determination of indicators such as mean score and the sentiment score (Arru et al., 2016). Based on this, the calculation of the mean score for the responses collected is denoted as Table 6.

Calculation of sentiment score for the responses collected is denoted in Table 7. The score was determined based on the consideration of positive responses obtained for the examined three main parameters.

Based on the values obtained for each of the mean score and the sentiment score values, the following conclusions of the decision making denoted in Table 8 can be defined (Arru et al., 2016).

As both the mean score and the sentiment score values result as less than 0.5 value, the perception level on the existing trust towards the MHEW mechanism is considered at a considerably lower level.

Table 6 Calculation of the mean score

Category type	Category	Percentage (%)	Q1	Q2	Q3	Mean score
Gender category	Male	62	0.358	0.289	0.035	0.227
	Female	38	0.461	0.262	0.072	0.265
Age category	Below 25 years	1	0	0	0	0
	26–45 years	36	0.497	0.320	0.026	0.281
	45–60 years	46	0.270	0.239	0.050	0.186
	Above 60 years	6	0.455	0.455	0	0.303
	Not given	11	0.536	0.241	0.027	0.268
Overall mean score			0.368	0.258	0.03	0.219

Table 7 Calculation of sentiment score

Score values	Q1	Q2	Q3	Sentiment score
	0.402	0.280	0.035	0.239

Table 8 Decision making scores

Score	[0;0.5]	[0.5;1]
Level	Very low	Very high

4.3 Correlation of Determination (r^2)

The correlation analysis was thereafter conducted using the IBM SPSS software with the basis of examining the relationship between the variations of the trust level based on the experience of being a first responder. This approach was used here to evaluate the relationship between the two independent variables. Correlation of determination is a statistical measurement that assesses how strong the relationship between two variables. Along with the variation of one variable, this assesses how much the other factor varies.

For this to be examined, the graphical representation was done by modeling the variation of the two main parameters considered. These two parameters are defined as the number of years of experience and the number of people whose trust level remains the same with the time. Here the best-suited curve based on the consideration of linear, polynomial, power, exponential and logarithmic variations were examined based on the value obtained for the coefficient of determination (r^2). The value of the obtained r^2 values with the variation in the trend line patterns are represented in Table 9.

The graphic representation for the most suited trend line pattern on polynomial behavior is represented in the below Fig. 3.

Table 9 Trend line behaviors

Trend line behaviors	Value of the r^2
Polynomial	0.99
Linear	0.82
Exponential	0.93
Logarithmic	0.96
Power	0.94

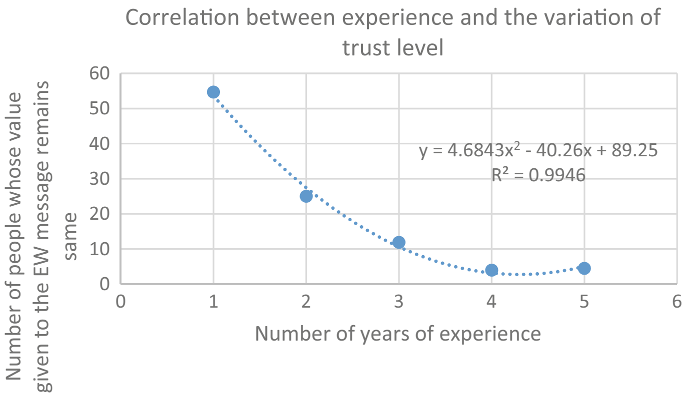

Fig. 3 Polynomial behavior of the variables

As the coefficient of determination value is greater than 0.7 value, it is considered that there is a strong negative correlation among the increase of experience as the first responders and the number of people whose value given towards the MHEW mechanism remains as same, as also identified by Menard (2000). Based on these results, with the increase of the experience as the first responders, the value given by the first responders on the MHEW messages is considered considerably less. With the increase of experience, their adaptation towards trusting or not trusting the MHEW messages become varied with consideration of the external influencing factors. The results obtained here is more biased with the experience of the first responders in the considered sample size.

5 Discussion

The stakeholders who are related to the downstream level of the MHEW mechanism in Sri Lankan mainly comprises of community level and the first responders. In this study, the focus was directed towards an examination of the trust level of the first responders towards the existing MHEW mechanism in the country. This perception level was examined based on a telephone interview which was conducted with the collection of 1004 responses from the survey.

From the results obtained from this indicator determination, the perception of the first responders is revealed at a lower level with the consideration of both the scores obtained for mean score value of 0.219 and the sentiment score value of 0.239. Further, the correlation among the two considered variables of experience as a first responder and the number of people whose trust level on the MHEW mechanism not varying were examined. This was mainly determined through the development of the best-suited trend lines with the variation of the two variables where the coefficient of determination for each of the linear, polynomial, exponential, logarithmic and power behaviors was modeled. From the results obtained, the closer coefficient of determination value of 0.99 resulted in the representation of the polynomial behavior among the two variables. This mainly revealed that there exists a strong negative behavior between the variation of the experience as first responders and the number of people whose trust level is not varying. The results support the idea that most of the people who are adapted to the new technologies and modes of delivering MHEWs become more familiar with the level of credibility of the information delivered. This way, these people become more familiar with the EWs delivered through the mechanism with the experience they have obtained engaging with the system.

These results were thereafter compared with the community level trust behavior examination which was conducted as part of another research study in Sri Lanka (Shehara et al., 2020a, 2020b, 2020c). This was focused mainly to identify the existing perception level of both the community and first responder stakeholders who are considered the most significant in the downstream level MHEW dissemination. The comparison of these concerns on community and first responder behaviors on the trust of the MHEW mechanism in Sri Lanka is discussed further in the below section.

5.1 Comparison of the Community and First Responder Perceptions on Trust

From the results obtained through examining the community level trust examined in the Sri Lankan context towards the MHEW mechanism, the following results were revealed (Shehara et al., 2020a, 2020b, 2020c). Here the determination was conducted with the implication of the fuzzy logic approach in the decision-making approach. The comparison of the results obtained from both the studies is represented in Table 10.

The overall summary of the responses obtained from both the community and first responders related to the MHEW mechanism is denoted under Fig. 4. In this representation, the strength of the trust level based on the impact of each of the defined variables are represented through the thickness of the arrow mark. Further, the (+)ve and the (−)ve signs mainly denote the impact of the increase of defined variables towards the trust level of each of the community and first responder levels.

Table 10 Comparison of community and first responder trust behaviors

Community trust perception	First responder trust perception
• Trust towards the delivery of the EW alerts delivered through the mobile phones towards the community level • The urban level trust level is higher when compared with the rural level community trust level towards the delivery of MHEWs through mobile phones • Most trusted authorities in MHEW delivery is the Disaster Management Center (DMC), Sri Lanka Police (SLP) and the Media	• Trust level on the existing MHEW mechanism is at a lower level perception • With the increase of the experience as the first responders, the people whose trust level on the MHEW mechanism remains stable decreases

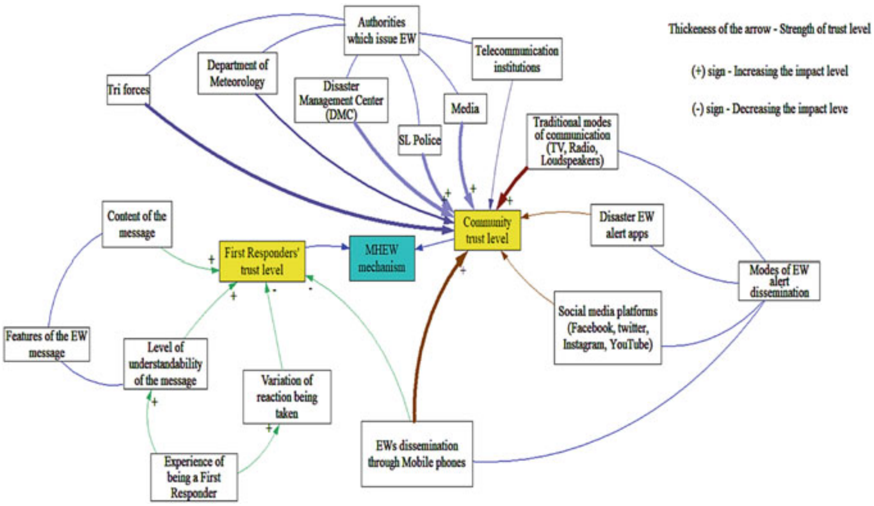

Fig. 4 Summary of the trust level responses

It was revealed from the previous studies that the authorities which are issuing the EW alert highly influential over the community trust level. The extent of the community trust level is very much high when the EWs are issued through tri forces, DMC, SL police and media. Further, there is a higher impact on the community level when the EWs disseminated through traditional communication modes like TV, radio and loudspeakers. This is much higher in comparative to the modern communication modes like social media platforms and disaster EW alert apps. Further, the community trust level is more biased towards adaptation on trusting the EWs delivered through mobile phones as the text alerts. In the existing MHEW mechanism, the trust level of the first responders towards the alerts delivered through mobiles phones seems to reduce. Moreover, with the content of the message and extent of understandability of the message, the trust level is seems increasing among the first responders. Further, it was revealed that with the experience of being a first responder, the variation of the reaction being taken in adapting to the situation becomes increased. With this, people tend towards reducing their extent of trust level on the EWs delivered through modern communication modes like mobile phones. This overview of the variation of extent of trust level with the considered parameters are graphically illustrated in Fig. 4.

5.2 Summary

The first responders and the community level are considered two of the key stakeholders who are interlinked with the downstream level of MHEW mechanism in the Sri Lankan context. An identification of the strengths and weaknesses in the existing mechanism of MHEW communication and dissemination, it is necessary to examine the extent of the perception of trustworthiness. These are mainly identified through the comparison of the results obtained from the two studies which are based on the stakeholder trust level at the downstream level of MHEW mechanism.

Based on the first responder's perception level, the extent of trust level on the existing mechanism of MHEW dissemination was revealed at a lower level. This was revealed through the results obtained for mean score and sentiment score for the perception level indication on trust. From the low value obtained for both the measuring indicators, this result was interpreted. The results obtained from the correlation determination of the two variables of experience as a first responder and the number of people whose trust behavior does not variate denoted a negative polynomial behavior. The strong negative relationship between these two variables could be generalized as a common phenomenon based on the analysis results.

From the comparison of community and first responder level trust behaviors, the community trust towards the MHEWs that are issuing through Disaster Management Center (DMC) was at a very high level. But the first responders have less faith in the existing mechanism though they are known that the alerts are issued through DMC in Sri Lanka. Further, the fuzzy logic approach was used in the determination of the trust over the delivery of the MHEWs through mobile phones towards the community level. The results here indicated that the communities are more likely to adapt to the system of delivering MHEWs through mobile phone technologies. This was emphasized with the determination of the triangular fuzzy numbers based on the fuzzy logic approach. Further, the urban and rural level comparison of the trust perception denotes that there is a higher level of perception by the urban level community towards the adaptation of dissemination of MHEWs through mobile phone technologies.

Accordingly, based on these research findings, the key focusing areas which need to be strengthened in the effective delivery of the MHEWs have been identified. These need to be integrated with the policy perspectives and as well as initiating the new digital approaches in reaching the community through the fastest and most accurate delivery modes of communication. Further, at the downstream level of the MHEW dissemination, the awareness of modern approaches of communication needs to be enhanced with more training and awareness session practices.

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Annex—Survey on First Responders

This is a survey is conducting as a part of research study undertaken by Department of Civil Engineering, University of Moratuwa and Dialog Axiata PLC. The main objective is to investigate the response of the first responders towards the technological applications associated with Multi-Hazard Early Warnings in Sri Lanka and to identify the past experience and benefits of being selected as a first respondent in the Early Warning alert dissemination process.

Demographic Information

1. What is your gender?
   Male
   Female
2. What is your age?
3. What is your hometown?
4. What is your desgination and authority?
5. Are you receiving disaster Early Warning messages alert messages to your mobile phone through Dialog verified by the DMC (Disaster Management Center?
   Yes → Skip to Question 6
   No → Skip to Question 17

Identification of the First Responders

6. Are you aware that you are receiving Early Warning alert messages to your mobile phone through Dialog verified by the DMC (Disaster Management Center)?
   Yes → Skip to question 7
   No → Skip to question 12

Past Experience as a First Responder

7. How long is your experience as a first responder in receiving Early Warning messages related with hazard incidents?
   1 year
   2 years
   3 years
   4 years
   5 years
   More than 5 years
8. What is your level of satisfaction of being a first responder in receiving Early Warning messages during hazard incidents?
   Very high
   High
   Moderate
   Low
   Not satisfied
9. What was your first reaction to the message received over the mobile phone on a potential disaster incident ? Check all that apply.
   Searched for more information
   Got alert from other communication mode before this
   Made aware the responsible authorities
   Made aware the community
   No any action

Not received such critical messages on potential disaster incident
Other (Please specify)

10. Is there a variation in the first reaction undertaken from the beginning till now?
Yes
No
11. If yes, please mention the variation of reaction

Opinion on the Text Message

12. What is your opinion on the content and understability of the text message received to the mobile phone? Check all that apply.
Content is enough
Content is too much
Content is not enough
Content is understandable
Difficult to understand the content
13. What do you think of the level of efficiency of receiving Early Warning message to your phone as a first responder? Mark only one response
Very high
High
Moderate
Low
Very low
14. What are your suggestions to improve the functioning of the Early Warning message delivered to the mobile phone?
15. What is your level of interest of being a first responder in receiving Early Warning messages during hazard incidents? Mark only one oval.
Very high
High
Moderate
Low
Not interested
16. What is your preferred language in receiving Early Warning messages to the mobile phone? Mark only one oval.
Sinhala
English
Tamil
Singlish
Tanglish

Identification of responsibility in DM mechanism in SL

17. Do you have a responsibility in Disaster Management mechanism in Sri Lanka? Mark only one oval.
Yes → Skip to question 18
No → Skip to question 21

Responsibility in Disaster Management Mechanism

18. What authorities are you responsible of sharing the information received regarding potential disaster incidents?
19. How many people are you making aware (or capable of making aware) regarding the Early Warning alerts in potential disaster conditions?
20. What are the modes of dissemination of Early Warning alerts towards other stakeholders from you? Check all that apply.
    Phone calls
    SMS
    Emails
    Word by mouth
    Letters
    Other (Please specify)

Special Section

This section needs to be filled after completion of the phone survey by the survey coordinator. The answers should be filled based on the opinions given by the responder during the phone call.

21. What is the level of power of the responder in decision making related with Disaster Management mechanism in Sri Lanka? Mark only one.
    Very high
    High
    Moderate
    Less power
    No power
22. What is the level of hierarchy of the responder based on the responsibility associated with Disaster Management mechanism in Sri Lanka?
    Regional
    District
    Provincial
    National
    International
23. How many people work under him in the relevant authority (rough number)?
    No one
    Less than 5
    6–10
    11–15
    16–20
    More than 20
    End.

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Folk Religious Practices as an Indigenous Approach to Negotiating Disaster Risks in Sri Lanka

Anton Piyarathne

Abstract The Sendai Framework for Disaster Risk Reduction (SFDRR 2015–2030) has emphasised an integrated and holistic approach including culture and heritage in addressing disaster situations. In this context, the current paper explains how folk religious practices of ordinary villagers living in the eastern coast of Sri Lanka have helped them to cope with the Tsunami in 2004. This research paper is based on a theme identified during a long term phenomenological study conducted on how ethnic and religious dimensions shaped the everyday social lifeworld in the rural village of Pānama between 2010 and 2012. The paper details how the villagers claim they were protected by the Goddess Pattini during various disastrous situations in general and the Tsunami in particular. The people of the eastern coast are generally traditional believers of Goddess Pattini—a goddess of prosperity (which includes security or protection and sustainability as well), who has historically cared for them. Their everyday social lifeworlds are shaped by this belief system enriched and informed by folk religious traditions. In times of strife the Goddess Pattini appears in the dreams of a few holy people in the village and provides forewarnings about precarious situations. Prior to the Tsunami this lead the entire village to gather in the village shrine room, the Ampitiya Devālaya, to perform rituals which acted as a mechanism for awareness creation and preparation that reduced the disasted risk of the community and ultimately saved their lives.

Keywords Disaster prepradeness · Folk religions · Cultural heritage · Embodiment of culture and heritage

1 Introduction

When I was searching for a rural research site, I was advised by some of my teachers and colleagues at the University of Colombo to go to the "east" where inter-ethnic collaboration was considered to be relatively well developed. At the time, I had

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little experience in eastern Sri Lanka. I was curious as to how such a unity could exist when there had been so much ethno-nationalist violence in other parts of the country during the war years. While I looked for an entry point to the “east” driven by curiosity about this culture of co-existence, I was offered an opportunity to join a five-day field training programme organized for sociology undergraduates of Ruhuna University. I wondered how these monolingual (Sinhala speaking) students and staff travelling in two big buses were going to conduct successful field training in the East coast which was predominantly Tamil speaking. According to my conventional understanding people in the east were Tamils and Muslims. I also believed that there was significant hostility between Sinhala, Tamil and Muslim communities during the war, as in other parts of the country, and never expected to see coexistence in eastern Sri Lanka—particularly Pānama and Pottuvil which were the field visit sites. I still remember how afraid I was when I heard that shootings had taken place in a neighbouring area when I visited Sainthamaruthu to do a few lectures for a diploma in counselling programme jointly conducted by the South Eastern University of Sri Lanka and a Colombo based Non-Governmental Organization (NGO).

There are not many anthropological studies of the east of Sri Lanka. The first anthropological exploration of people living in this part of the country was by Nur Yalman in his monograph, Under the Bo Tree (1967) followed by Dennis B. McGilvray who did research on caste, marriage, and the matriclan structure of Tamils and Muslims. His recent research Crucible of Conflict (2011) is dedicated to discussing Tamil and Muslim society in this part of the island. The east is presented in recent anthropological writings as a location where there is a considerable level of inter-ethnic relations, co-residence, inter-marriages between ethnic and religious groups, and religious cooperation (Yalman, 1967; Obeyesekere, 1984; Mc.Gilvray, 2011). This study covers two locations in eastern Sri Lanka—Pānama and Pottuvil which fall under the jurisdiction of the Ampara District Secretariat. These two places were conflict zones frequently described as border villages, where both the civic and civil life of ordinary people (often referred to as “samanaya minissu” in Sinhala) was caught in a tense grip between the LTTE (Liberation Tigers of Tamil Eelam) and the government armed forces.

Is it possible that members of two ethnic groups which are seen as conflictual on a national scale but live in this micro social system have inter-connected through kinship and marriages, religious beliefs and practices and a caste based economic system? This notion of a longstanding relationship does exist in Pānama. In an ethno-nationalist war, powerful parties are involved in territory-acquiring-battles to safeguard their interests. These agents of conflict are not concerned about social networks or the perception of the locals regarding the causes that drove the respective parties to war. Perhaps the causes of war were produced by both Sinhala and Tamil elites who remained aloof while others, often comprising members from non-elite families on the ground, kept killing each other. In a way, the east in general and Pānama in particular could be considered a place where both the government forces and the LTTE confronted the notion of people who could not be measured according to their own divisive ethnic yardsticks. The government forces could not find pure “Sinhalas” and the LTTE cadres struggled to trace pure “Tamils”.

Pānama society can be interpreted as an already existing but invisible solution for problems created within the ethno-politically divided modern Sri Lankan society. The people of Pānama have been maintaining a unique social and cultural system in which statuses and roles have been defined for Sinhala and Tamil groups along caste lines. The villagers do not negotiate along ethnic borders but use castes to interact with different politically mobilised groups in other parts of the country. Rogers (2004) argued that the legitimacy for kingship was defined not alone ethnic but caste lines in the 18th Century in Sri Lanka in the Kandyan kingdom. Perhaps this characteristic may be still reflecting in Pānama community which is composed of the descendants from upcountry. This discussion of Pānama will explain how residents of Pānama have maintained intra- and inter-ethnic relationships through a caste based classificatory scheme despite the challenges posed by very trying times created by the war which resulted in people being suspicious of ethnic others. Pānama is also a good example of a remote village where both Tamil and Sinhala ethno-nationalisms were challenged and the social equilibrium of this micro social space survived. This social equilibrium whereby Sinhalas and Tamils live as high and low-caste groups appears to be the form of commongrounds discussed by Piyarathne (2018). Barth's (1969) notion of culture as the ethnic boundary faces a tough test in this context, because Pānama is a place where Sinhalas and Tamils live within one broad culture and heritage. The argument put forward by Harrison which discusses ethnicity and nationalism as relationships that explain denied or disguised resemblances without emphasising difference is applicable in Pānama (Harrison, 2003, p. 345). All the caste groups are included in one culture, but they perform various roles assigned according to the local classifications. This is similar to what Neofotistos (2004) discusses, where agreeable community participation is accommodated for all the social categories in one social system. In the next section Pānama village and its social system is discussed in greater detail.

1.1 Introduction to Pānama Village

I began longer ethnographic fieldwork in Pānama in March 2010. When Yalman did his research in the 1960s, the village population was 987 which has significantly increased to more than 10,000 persons living in five Grama Niladari (GN) divisions. For Yalman, Pānama was one of the most isolated villages in Sri Lanka located between large Muslim and Hindu conglomerations, like Pottuvil, Thirukkovil, Kalmunai and Batticaloa in the north and the small "Sinhala jungle communities" to the west (1967, p. 311). This "Sinhala jungle community" composed of 67 families lived in Kumana and were resettled in irrigated agricultural land in the Mahaveli new settlement area—a mega development project of the government formed by the United National Party (UNP) in the 1980s, parallel to the strategy of conserving the Yala National Forest. Ten out of sixty seven families are settled in an area now identified as Kumana Gammanaya (Kumana village) in Pānama that is close to their "lost home" from where they were forcefully evacuated. This might have happened due to their low-caste background as Padu people. The closest community to Pānama is Pottuvil which is a predominantly Muslim area which had about 7000 people during the time Yalman conducted his research (1967, p. 311). But this number has increased drastically today. The Tamil speaking people who live in the east coast are divided into many sub groups in terms of religion as Hindus, Muslims, Roman Catholics and Protestants. Hindus are further divided according to their caste background.

Pānama is home to both Tamils and Sinhalas. The Sinhalas identify the village as *gama*[1] (hereafter S:) while the Tamils call it *kiramam* or *ūr*[2] (hereafter T:). Both Sinhalas and Tamils add adjectives to claim inheritance or ownership of the village. Sinhalas use the adjective *ape* and Tamils use the terms *enga*, *engaludaya*, *engaluda* to denote "ours". In general, they use the plural sense to address the village which includes everyone—*apē gama* in Sinhala and *engaladu ūr*, *enga ūr* or *engaludaya kiramam*, *enga kiramam* in Tamil. In practice everyone refers to Pānama as "our village" which connotes solidarity and emotional attachment.

Villagers identify themselves as "Pānama people" (S: *Pānama minissu*) irrespective of caste or ethnic divisions. It seems that people coming from outside areas who are not connected to the culture of the east had started labelling them as "fifty-fifty" (S: panahata-panaha) people due to the ethnically mixed nature of the Pānama villagers. This labelling might have been frequently used during the war by outsiders such as members of the armed forces and government officers to denote the uniqueness of the villagers. The members of the armed forces were often confused during daily identity checks at security roadblocks. On one hand, this "fifty-fifty" discourse operated as a way in which Pānama people were defined by security officers. On the other, it also worked as a means of preserving the unique "Pānamaness" (S: *Pānama minissu*).

Pānama people use a unique vernacular language. Both Tamil and Sinhala used by people in Panama has unique differences compared to how Sinhala and Tamil are used in my other research sites in Colombo. The Sinhala people and Tamil people use same words in Pānama. They chase dogs yelling *hadi*, where the term *ada*, (man) used in Sinhala might have originated from Tamil *ade* (man). Some of the other common words used by both Sinhalas and Tamils are: *pingi* (row), *rottuwa* (road), *olunguwa* (narrow road), *abagannawa* (take a seat), *marikkiwenawa* (go), *bukul denawa* (hit), *ona* (chin), *gongaya* (crow), *atikitta* (frog), *hinno* (ants), *mappudiya* (a hand of paddy), *hura* (brother-in-law), *kundikora ennawa* (ukkutayen innawa), *kundukattuwa* (sleep in curve shape), *ambanawa* (chase), *Mattayo* (muslims), *brumpetti* (turbine), *wade* (rent), *kudilla* (a thatched house), *Vattavidane* (welvidane), *Vattandi* (a position in the Ampitiya ritual, an wadanna). My association with the Pānama people during extended field work showed that many of them were bilingual; the Tamil people were fluent in Sinhala and vice versa. Our neighbours, the low-caste Tamils often engaged in day-to-day conversations in Sinhala.

[1] Sinhala terminology and denote as S: hereafter.

[2] Tamil terminology and denote as T: hereafter.

Myself along with Aravinda, a young graduate from the Department of Sociology, University of Colombo, who assisted me in fieldwork, mostly lodged at an unoccupied small house in the village constructed under one of the many Tsunami housing projects funded by foreign donor organisations. This small house became our home (S: *apē gedara*) from March 2010 to January 2012. It was a house with a living room, kitchen and a veranda. The toilet was constructed around 150 m away from the house because villagers considered attached bathrooms a threat to hygiene. The house had a sandy garden. It was the last house in the by road of Abeysinghepura. We were about 500 meters away from the sea, which often made us nervous due to Tsunami rumours and warnings. Sand-made mountains eased the tension somewhat because they served as barriers in the front of our house. Moreover, on most mornings we found foot-prints of wild elephants around our house. Our neighbourhood was made up of around 20 Sinhala high-caste as well as low-caste Dhobi families. We were welcomed to the neighbourhood network. We also intiated *ganu denu* (S: give-and-take relationships) with friendly neighbours. They sent us curry dishes, cooked by the wives with portions of the fish brought home by fishermen. We fetched water from the well of a high-caste Sinhala neighbour as our well was used for bathing. We borrowed the air pump from a Dhobi family to pump air for our bicycle. Two villagers, a youth and an old trader, were kind enough to lend us their bicycles from time to time to go around the village. Whenever we wanted to eat fish curry, we would go to the seashore where the fishing-boats and canoes were parked. This was a location which served as a natural fishing harbour. Muslim, Tamil and Sinhala middle-level traders came from Pottuvil, Ampare and other places to buy fish in lorries equipped with cold storage facilities. The Pānama fishermen used to give away a quantity of free fish enough for a *hodda* (S: curry) to those who came to the harbour at the time they reached shore in the morning and evenings. Caste is not a factor when they distribute fish. Even the fisher folk themselves are mixed. We engaged in everyday casual talks with the neighbours. Children and adults of all caste groups used to come to our house for a chat. We were careful to ensure that Dhobi family members were not at our house when the high-caste visitors came to see us. The high-caste Sinhalas, including the landlady, did not approve of our association with Dhobi people. However, as visitors to the village we were smart enough to strike a balance. Routinely we participated in important events of the village such as funerals, weddings, and rituals at the temple and devālayas (shrines).

The high-caste Pānama people were regarded as hailing from Sinhala warrior families who withdrew following the 1818 *Uwa-Wellassa* riots fought against the British in the hill country of Sri Lanka. The then British Governor, Robert Brownrigg issued a gazette notification condemning persons rebelled against British rule in Sri Lanka. The rioters were called “traitors” and their possessions were confiscated (Kostal, 2000). This Gazette notification was changed only in 2011 and those who participated in the uprising were honoured as “National Heroes”. However, the educated people of Pānama assert that they have been living in Pānama before the warriors came in 1818. There is a claim about a link between Pānama people and the indigneous aboriginal community called Vädda in Sri Lanka—referred to as the

Halawa Paramparawa (S: *Helawa* generation). This mix is "taken for granted" in everyday life like the high-caste Sinhala-Tamil mix.

I believe that we cannot fully comprehend the Pānama social system by superficial observations that are laden with various biases such as ethnicity, class, gender, and politics. Pānama should be understood from the perception of the 'Pānama people' which necessitates long-term acquaintance with Pānama. I only realized that my approach shaped by the domiant ethnic lens was inappropriate after a few months had passed. Initially I was identifying various groups as "Sinhala people", and "Tamil people" and using a vocabulary that was loaded with ethnoreligious biases. Subsequently, I understood the difference by juxtaposing myself with Pānama people. The vocabulary of the Pānama people is composed of caste references but not ethnicity: *Dhobi minissu* (S: Dhobi people—washermen), *honda kattiya* (S: high-caste people), *ape kattiya* (S: our people), *ēgollange kattiya* (S: their people), *ēgollan* (S: they), *megollange kattiya* (S: these people's clan). They refer to ethnicity routinely when talking to outsiders to cater to the worldview of the outsiders. Outsiders like me often came wearing ethnoreligious lenses.

Obeyesekere (1984) and Yalman (1967) identified Pānama as a "shatter zone" where there is a substantial degree of intermarriage, ritual collaboration and ethnic merging. I endorse Yalman's recognition of Pānama as a merging of Sinhala and Tamil social systems. He observed this amalgam of kinship, caste and religion as those three spheres create the traditional idiosyncratic social system of Pānama. Following is a very brief discussion of these three aspects in order to better dileneate the embodiment of the social-cultural system and heritage which is the main analytical focus of this article.

1.2 The Caste-Based Social Structure of the Village

Pānama has four castes: *Goyigama* and *Vellālar*, *Dhobi*, *Barber*, and *Padu.* This is a combination of Sinhala and Tamil castes which forms one unique social system in the village. In general Sinhala high-caste *Goyigama* and Tamil high-caste *Vellālar* are identified as equal status caste groups by writers such as Sabaratnam (2001). According to the inter-caste relations of traditional Pānama, the *Goyigama* and *Vellālar* people have enjoyed the highest respect from the other three castes. The next two caste groups: the *Dhobi* (T: *Vannar* washermen) and the *Barbers* (hair cutters) (*Navitar barber*) are also Tamil caste groups as explained by McGilvray (1982) in relation to the neighbouring areas of Akkaraipattu and Kokkadicholai. The last caste group in the hierarchy *Padu* is an ethnically Sinhala group. There are arguments regarding the Sinhala people's exclusive claim to the *Goyigama* caste. In-depth discussions with Sinhala villagers who came as seasonal fishermen to Pānama initially supports a caste-mixed view and suggestive that these are not *Goyigama* people as often claimed in everyday discussions. These low-caste people who have joined the village community from low country areas have been elevated to high-caste positions. The up-country Sinhala warriors who came to Pānama married into high-caste *Vellālar* Tamil families. These two caste groups were very cautious never to inter-marry with the *Dhobi* people. There is no indication of high-caste Tamils and low-caste Tamils uniting on the grounds of ethnicity even during the peak period of the war.

1.3 Marriages, Kinship and Property Inheritance

In their everyday social lifeworld, Pānama people use kinship terminologies to address fellow villagers. Some such commonly used terminologies are; *māmā*, (S: uncle), *bāppā* (S: big father–fathers' brothers), *nandā* (S: aunt), *seeyā*, *muttā* (S: grandfather) *āchchi* (S: grandmother), *akkā* (S: elder-sister), *nangi* (S: younger-sister), *aiyā* (S: elder-brother), and *malayā* (S: younger-brother). The high-caste Tamils were also given the same social positions according to what I overheard in day-to-day conversations. The usage of uncle and aunty in relation to washermen and washerwomen is also observed; *redi nendā* (S: *Dhobi* woman) *redi mamā* (*Dhobi* man).

The most important dimensions of the social lifeworld of a member in South Asia in general and Sri Lanka in particular—such as marriages, kinship and inheritance—are shaped by a caste based social system and beliefs that have prevailed for generations in this village. By and large, marriage has bonded two ethnic groups which view themselves as rivals in contemporary Sri Lanka as blood relatives, kinsmen and kinswomen, across all layers of the caste groups from the time Yalman (1967) did his fieldwork. This was convincingly proved to us when we took part in the marriage of a young man of mixed ethno-religious background to a Tamil girl from Thirukkovil, a predominantly Tamil area. The marriage took place at the bride's house in Thirukkovil. Aravinda and I accompanied the Sinhala relatives of the bridegroom who went to the Tamil village to participate in the wedding in a bus. The bridegroom's mother is Sinhala and the father is a Tamil man from Batticaloa. Even though the father had disappeared during the war, the father's relatives continued to maintain a very close relationship with the bridegroom's mother who lived in Pānama. They also played a very active role in the wedding. The bridegroom's elder brother had also married a Tamil Hindu girl from Jaffna. A Pānama Sinhala lady who is another relative of the bridegroom told me "I will find a bride for my son also from this village." During this trip we walked with the Pānama team to visit at least five houses where a few other Pānama Sinhala people had married into that village.

Yalman (1967) identified that the Pānama kinship pattern is as an amalgam of Sinhala and Tamil systems. This is a result of Sinhala-Tamil mixed marriages, *binna* (S:), through which they establish blood-relations, *retta uravu* (T:) or *le nekama* (S:) in all the caste groups respecting the fact that marriages happen between parallel caste groups in the Sinhala and Tamil communities. However, the marriage between two different castes is banned and those who do so are compelled to leave their high caste status. The high-caste Tamils and Sinhalas have blood relationships through marriage. This situation led nearby villagers to call Pānama people *kawalam* (S:

mixed)—a discourse which has a long history as Yalman observed a similar situation in 1955.

Inheritance happens through the *binna* marriage practice that exists in the village. These are endogamous marriages in the sense that the marriages takes place within equal status Sinhala and Tamil castes. They all practice *binna* (matrilocal) marriages irrespective of the ethnic, caste or class backgrounds. People maintain kinship ties with both Sinhala and Tamil relatives on a daily basis. In a *binna* marriage the husband lives with the wife while the wife goes to live with husband in *deega* marriages that are practiced in most parts of Sri Lanka. The *binna* marriage pattern exists in Pānama and elsewhere in the eastern province among the Muslims, and Tamils coupled with dowry, *dāvädda* (S:) or *seedanam* (T:) where the rich people buy land and build a house while poor parents give their own thatched house to the daughter and build a *kudilla* (a small house) in a corner of the same land or provide a different land after *kelē kotagena* or *wal kapalā* (S: clearing some bush areas).

1.4 Goddess Pattini and Other Religious Beliefs in Pānama

Worshiping Goddess Pattini and God Kōvalan (T:), Gana deiyō (S:), popularly known as Vināyagar (T:) or Lord Ganapathi of the Hindu pantheon, and God Murugan (T:), Kataragama deiyō, Kanda Kumāra (S: God Kataragama) is part and parcel of the long lasting religious traditions of the village. Goddess Pattini plays a very important role in shaping the belief system of the villagers as the deity responsible for prosperity and safety and as the main guardian deity. The religious life of Pānama people is full of ritualistic performances taking place in devālayas (shrines)—mainly in the Ampitiye devālaya, where a shrine complex with two shrines has been built for Goddess Pattini (T: Amman) and her consort, God Aluth Bandara or prince Pālanga in Sinhala (T: Kōvalan) under the shade of two huge tamarind trees, in an isolated corner of the village facing the paddy fields. During this ritual all the Pānama villagers irrespective of gender, caste, ethnic or religious backgrounds are conventionally divided into two generational groups: *udupila* (S: upper side) to represent God Kōvalan or prince Pālanga, while *yatipila* (S: lower side) represents Goddess Pattini. There are rituals to be performed if someone wants to change this ascribed status such as during marriages. The annual religious festivals, *Ankeliya* (S: horn-pulling) or *Kombu Vilayattu* (T:) rituals of Pānama start with the participation in the annual religious festivals of Kataragama devālaya (shrine) that last for fourteen days. The identity of the people here is shaped by common religious beliefs and practices. They visit recently built Buddhist temples and traditionally owned Hindu shrines. Yalman also saw a lot of similarity between Buddhism and Hinduism in Pānama. The same pantheon could be seen in both religious practices (Yalman, 1967, p. 316). Pānama has two Buddhists temples: one for Buddhist monks and the other one for Buddhist nuns. There are two Hindu temples that are identified as *devālayas* (S:) *kovils* or *koils* (T:): Pulleyar Kovil (T: shrine) or Gana devālaya (S:) dedicated to God Pulleyar (T:) or Gana deiyō (S:). In addition, the villagers have access to other devālayas located in the forest area closer to the village: Kuda Kebilitta, Maha Kebilitta and Okanda devālayas which are dedicated to Lord Murugan.

One of the main religious activities in the village is worshiping Kataragama deiyō (S: God Kataragama) according to the Sinhalas and as Murugan, Skandakumara, Kartieya by Hindu-Tamils, as Italeyakā (demon of the arrow) by the Vädda people and also as Vanniya by people of Vanni. They take part in annual religious festivals of Kataragama devālaya that last for fourteen days. Kataragama is a multi-religious site. It contains Kataragama deiyō's shrine as well as shrines for his two consorts, Theyvanai-amma (Indian wife) and Valli-amma (Sri Lankan consort), the Kiri Vehera (a Buddhist temple), a mosque and a shrine. Apart from the religious places in the site, there are Hindu and Buddhist places of worship in the vicinity as well. This religious site is located on the bank of the Manik Ganga (Manik river), where all the people take a holy bath as part of a purification process before they approach Kataragama deiyō. The devotees who come to Kataragama either take vows before God Kataragama or perform rituals in his name. They do this in the hope of achieving success. Some devotees perform rituals which involve physical torment such as piercing the body with pins, needles or pointed iron sticks (S: *katu gaseema*), hanging down on hooks (penetrating their skin), rolling in worship across the holy ground and fire-walking. Others show their devotion by performing the *Kāvadi* dance. In general, almost all the people visiting Kataragama offer a *pūja wattiya* (S: offerings) to the God.

The Hindu Tamil devotees start their annual pilgrimage on foot (S: *Pāda Yātra* or T: *Pāda Yāttirai*) from Jaffna Nallaur temple, traveling through Trincomalee, Batticaloa and Pottuvil to Pānama and walk about 450 km in total, including traversing the Yāla National Forest to reach Kataragama (the place of the God Kataragama is also identified as Kataragama). This is one of the major events in worshping God Murugan or Kataragama in Sri Lanka. From Pānama they walk another distance of 105 km which takes 4–8 days. I suffered many water blisters during this track and had to lie down on the sandy bank of the Manik Ganga (S: river) for a whole day which slowed the trip of the *Sami*'s (term used by Tamils and Sinhalas to call pilgrims) in my group who engage in the pigligrimage to worship God Murugan. Buddhist Sinhalas who live in the eastern province, including those who are in Pānama, also accompany their Hindu Tamil counterparts. A few years ago, the pilgrims used to stay in Pānama, *Kittange*, for a few days to rest before entering the Yāla forest as indicated by some local writers such as Gunasekara Gunasoma (1994), and Kiribanda (2011).

1.5 Peoples' Belief Regarding the Protection of Goddess Pattini

During the field work I heard many stories of Goddess Pattini's intervention in protecting the village from disasters which can be broadly divided into two categories: manmade and natural disasters such as the Tsunami. Given below are two brief examples of man-made incidents which occurred during the wartime and were connected to the LTTE and the military.

(a) ***Manmade disaster***: This village was a border village during the war. The LTTE even maintained a police station in the village. Both the LTTE and state security personnel were confused as they could not differentiate these people on the basis of ethnicity. The popular story is how the LTTE attempted to attack the village, emerging from the Yāla National Park. As they approached the village, the villagers believe, the Goddess Pattini appeared as a platoon of government STF (Special Task Force) soldiers which frightened the LTTE battalion and dissuaded them from attacking the village. The second story also followed a similar pattern. Individuals had their own private stories to share about how Goddess Pattini saved their lives during the war.

(b) ***Natural disaster-Tsunami***: During the research I heard at least three stories connected to Goddess Pattini appearing in the dreams of holy people in the village prior to the Tsunami. Among them were the *Kapuva* (S: The lay clergyman performing rituals at the devālaya) and one of the patrons of Yatipila devālaya of Ampitiya shrine. The Kapuva of the lower side shrine told me how he had a dream warning of a Tsunami after four to five years of assuming duties at the shrine. "I started to believe in dreams after this dream. I normally sleep in a *Būru Enda* (S: camp bed). While I was sleeping, I felt that we were going to perform the water cutting ritual (S: *Diya Kepeema*, which is the last ritual performed to mark the end of most religious activities such as annual processions), but I did not have anything needed for the ritual in hand. I was thinking about this as well. I saw many people were walking with me. Eventually we went up to the sea where we perform the ritual. There we performed *madayak*, a *pūja* (offering) reciting certain stanzas. Following this offering those people who want to perform various rituals are supposed to come to the water and perform their rites. However, when I looked at the sea, I saw no water. I could see only stones and logs. I was walking further into the sea and when I looked back, I noticed that people were still standing at the beach. When I looked back at the sea again, I spotted high waves approaching me. I was frightened and started running back to the seashore. The high waves were chasing me. I was screaming *māwa allapalla* (S: do hold me). Suddenly I felt a woman catching my hand (I assumed that person was Goddess Pattini). I woke up to find my wife and mother-in-law standing next to my bed. When I got up, I asked myself "if it really happened it will not only affect me but the entire village, wouldn't it?" The following morning, I continued my normal farming activities and went to the paddy field. I did not do anything about it for seven days (seven is an important number in their belief system).

Meanwhile, the Goddess Pattini had appeared in Moorthy's dream and had told him that she had appeared in a dream to the *Kapu Mahattaya* (or S: *Kapuva*) but he had not done anything and suggested that he should do something about it. Moorthy then shared this story in the village bazar. People came to know about this. Later, one day somebody told me about this. I still did not take it seriously even though people were quite serious about it. My family members also told me that people came home inquiring about me. Another day when I went to the devālaya it was cleaned and swept well. I was wondering about this. Then Moorthy and his team came, and admitted they had done the cleaning. Moorthy asked me whether I saw a dream. I denied it as my father had advised me not to tell the truth about my religious life to others. When Moorthy informed me that it was the Goddess Pattini who had told him about this, I felt so serious and prayed to the goddess in tears (crying is considered a way of apologising in this culture). Then we all got together and performed a pūja with the stuff collected from the villagers. The Tsunami wave hit the country within a few weeks' time of the *Sakkara dāne* (special alms giving)." These alms giving were done in various other similar shrines located in the boundaries of the village.

Moorthy is a Tamil man around 45 years old, married to Gnana, a 40 year old Sinhala woman who was the Grama Niladhari of the area where we were stationed throughout the research. His father had come to this village from a Tamil area called Thambiluvil to work as an astrologer. He was integrated to Pānama society after marrying the mixed Sinhala-Tamil woman. This Tamil man had held the position of village leader and was the manager of the cooperative shop during the traditional healing ritual called *mada thabeema* (S: offering). He also served as a local doctor of the Siddha ayurvedic tradition. Moorthy inherited his father's knowledge of treating serpent bites and now serves as a *Sarvanga* Ayurvedic (S: local general physician) doctor in the village. He is a highly respected person in the village. Moorthy currently serves as the President of the Yatipila devālaya as well. Moorthy, as a very devout, and exemplary or "good" (S: *honda* or *silvath*, T: *Nalla*) person in the village receives messages from Goddess Pattini regarding the village through dreams. Prior to Tsunami in 2004, the god had appeared in one of his dreams and shown him the disaster. After that all the villagers got-together and offered a series of pujas at the Pattini devālaya and at the Buddhist temple. The forewarned people were safe though thousands died all along the eastern coast. Though the village is located on very low ground by the side of the sea only one man died due to the Tsunami. The Tsunami water surrounded the village, but people were ready. This is considered a miracle and another instance of Goddess Pattini saving the village. Moorthy's wife recalled the consequences when dreams were ignored on earlier occasions. Just prior to the killing of 18 villagers in the Yāla forest (alldgedly by the LTTE) the Goddess Pattini had given a warning through Moorthy but the villagers took little notice. They paid the price by losing 18 persons. It was a disaster that could have been averted according to Moorthy's wife.

Jayasinghe a 50 year old fisherman who was catching prawns with his wife in the lagoon when the Tsunami waves hit the village bore testimony to the above story. He said "There was a loud noise, trees started shaking and when I looked at the lagoon I saw a high tide and higher waves approaching the land. I suddenly remembered, how the rituals were performed at Ampitiya devālaya and our village temple after Moorthy shared his dream with the villagers. I ran to the village as fast as I could and notified the villagers, which gave them time to go to higher ground." He had also seen the man who went to tend his cows when the waves hit notwithstanding previous warnings and preparedness. This statement is testimony of the effectiveness of disaster preparation through rituals performed at the religious places.

2 Analysis

Both Goddess Pattini's and Kōvalan's statues were brought from Uva-Wellassa by warriors escaping the defeat of the rebellion according to the chronicles. Not only the statues but the tradition of rituals has travelled with these warriors from one place to another as they searched for a suitable place with drinking water to settle and engage in farming. These people who ran away from the Uva-Wellassa area migrated to the eastern deserts and temporarily inhabited several places in which they performed rituals for the statues of the deities. Finally, these statues which are currently placed in the Ampitiya devālaya had been brought to the village from a place called Raddila which these people inhabited, before finally settling in Pānama. It was a woman from the *Dhobi* caste who had initially placed these two statues, following which the villagers built a *kudilla* (common terminology to denote a temporary hut). Eventually this place was developed with two buildings dedicated to Goddess Pattini and Kōvalan. This whole process of the evolution of today's Pānama villagers reveals the way people's knowledge had developed in comprehending the environment and their surroundings reducing vulnerabilities and maximising the chances of better living.

In this paper I explain the concept I have referred to as "commongrounds." Combining Pierre Bourdieu's idea of habitus and Michael Jackson's notion of the existential and intersubjective lives of human beings, I define commongrounds as:

"…inhabitants' continuous and creative efforts to live and relate to each other in fields of common endeavour informed by embodied (conscious or unconscious) understandings of the social and material world. To put it slightly differently, commongrounds involve shared dispositions and abilities to use cultural resources in distinctive, pragmatic and creative ways that best match emerging situations and contingencies, while taking account of external forces/limits that threaten local social living in its meeting of existential needs" (Piyarathne, 2018, p. 7).

The main subject matter examined in this paper helps me discuss more embodied expressions of commongrounds in assisting the existence of people by way of embodying culture which is the local knowledge and art of living and assuring well-being for all. If we assume religion is part of the broader culture which includes their comprehension of strengths, weaknesses, opportunities, risks and strategies to deal with uncertainties and means of assuring their existence, we can begin to grasp what happened in this village. It is more reasonable to assume that the current shape of the socio-economic, cultural, and political sphere of the people has been moulded by the historical processes through which they negotiated inhabiting thickly forested areas and harsh environmental conditions with dangerous wild animals—overdetermined by the threat posed by the British rulers who were searching for them to punish them for treason. In that sense, a substantial part of their socio-cultural embodied heritage, significantly if not completely, was shaped by a traditional knowledge and skills of negotiating natural and manmade hazards while maximising the prospects of living and thriving. The so-called holy people always dealt with the Gods and Goddesses and cosmological orders which mostly associated with construction and destruction, which in turn works as a means of mapping a future for themselves and the community. This shows us the capabilities of embodied culture and heritage which shapes the everyday community lives of people.

The culture and heritage explored above under commongrounds could be also interpreted from the point of self and embodiment. Since the human body has been considered as a background feature in traditional ethnography, it has often remained implicit in anthropological theories of culture, "which historically have been cast in terms such as symbols, meanings, knowledge, practice, customs, or traits" (Csordas, 1999, p. 181). In this context the life saving capacity these people have to foresee the future could be interpreted as an outcome of the embodiment of the "existential conditions in which the body is the subjective source or intersubjective ground of experience" (Csordas, 1999, p. 181). Expressed another way, "a paradigm of embodiment can be elaborated for the study of culture" (Csordas, 1990).

3 Conclusion

This paper has discussed how a group of villagers living in a coastal village called Pānama came to be forewarned about the Asian Tsunami which occurred in 2004—saving hundreds of lives. Goddess Pattini, the guardian deity of the village "appeared" to holy people who in turn carried out ritualistic performances in the village shrine called Ampitiya Devālaya preparing people for the unknown disaster to come. The whole belief system and ritualistic process served as a familiar and graspable medium to deal with unknown disasters such as the Tsunami. These rural folk who live in the "last village of the southern hemisphere", far away from centres of developed modern science, had embodied cultural practices for early identification and preparation for disasters. The paper discussed the longstanding belief system of the village which was examined through ethnographic fieldwork conducted using a phenomenological approach. The study shows the capacity of embodied culture and heritage that has facilitated people in dealing with natural or manmade challenges such as the Tsunami effectively. It is within this context that the consideration of culture and heritage can be contemplated very important factors in reducing distaster risks and preparing people to face disasters successfully in South Asia in general and Sri Lanka in particular.

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Public Addressing System in Religious Places as Early Warning Dissemination Nodes—A Case Study in Sri Lanka

A. M. Aslam Saja, S. M. Lafir Sahid, M. Sutharshanan, and S. Suthakaran

Abstract An effective disaster early warning system is instrumental in evacuation to reduce the disaster impact. In an end-to-end early warning cycle, an effective community early warning dissemination mechanism plays an important role. The identification of the population at-risk to which the early warning needs to be directed and the clarity of the risk communication with social and cultural awareness are two key attributes to enhance early warning dissemination strategy. The objectives of this study are two-fold: (1) to carry out a village level early warning dissemination system audit in 24 selected villages in three districts of Northern and Eastern Provinces of Sri Lanka, and (2) to assess the reliability of the existing public addressing systems such as loud speakers, bells and drums (same technical devices are used for early warning dissemination during disaster alerts) in 44 religious places in the 24 selected villages. The study provided set of recommendations to increase the effectiveness of the existing early warning dissemination method using the locally available resources and to develop the religious places as early warning dissemination nodes by improving the technical reliability of the existing public addressing systems.

Keywords Community based · Dissemination · Early warning · Risk communication · Sri Lanka

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1 Introduction

Prevention, Mitigation and Preparedness to disasters start with information. Better early warning dissemination systems have been instrumental in evacuating vulnerable groups, moving livestock to safety places, and mobilizing emergency services and resources. Early warnings transmit information to individuals, households, community groups and to the community as a whole, informing them about the potential emerging risks and what needs to be done in order to prevent or minimize the damage. A people centred early warning system has four key components: risk knowledge, monitoring and warning service, dissemination and communication, and response capability (UNISDR 2006). The dissemination and communication component of an early warning system is equally important to other components to make the early warning messages reachable to at-risk communities.

According to Sharma (1999), a basic community based last mile early warning dissemination system constitutes three attributes (phases) in its hierarchy: the ability to identify a potential risk or the likelihood of a hazard that threatens a vulnerable population, the ability to identify accurately the vulnerability of the population to which warning contents need to be disseminated, and the ability to communicate information to specific recipients about the threat in sufficient lead time and clarity. In each of the above phase, a number of key stakeholders are involved. In an early warning system, three key groups of actors involved: (1) the originators of the warning, (2) stakeholders involved in communicating and disseminating the warning, and (3) people receiving, believing and acting on the issued warning. Even though all these actors play a key role in an early warning system, this study focused mostly on the dissemination of early warning messages.

A Multi-Hazard Early Warning Dissemination System (MHEWDS) was established in Sri Lanka from the generation of early warning messages to the final receivers at the village level. In the MHEWDS, the key stakeholders (including relevant technical agencies) and methods in disseminating disaster early warning messages in each stage, from the originator to the last mile receivers are included. Although a comprehensive early warning system is well established, it is important to ensure its proper operationalisation and the reception of early warning messages by the community (last mile) (Hettiarachchi et al. 2018). In this context, this study was designed with two key objectives: (1) to carry out a village level early warning dissemination system audit in selected villages in Sri Lanka, and (2) to assess the reliability of the existing public addressing systems in public and religious places in the same selected villages.

2 Community Based Early Warning Dissemination Systems

An integrated approach for disaster preparedness planning is needed within a comprehensive risk-sensitive development planning process at community levels. Within such a disaster preparedness plans at the community level, strengthening early warning dissemination and communication capacity is one of the key components. UN (2016) defined an early warning system for disasters as "an integrated system of hazard monitoring, forecasting and prediction, disaster risk assessment, communication and preparedness activities systems and processes that enables individuals, communities, governments, businesses and others to take timely action to reduce disaster risks in advance of hazardous events" (p. 17). A detailed gap analysis to understand the reach of the early warning messages to the communities at-risk, the effectiveness of existing local practices in early warning dissemination, and communities' feedback on the effectiveness of existing early warning infrastructure locally are vital in any studies aimed at evaluating the existing community based early warning dissemination systems (UNDP 2009).

2.1 Existing Early Warning Dissemination Methods in Villages

The use of multiple early warning dissemination methods may be needed to ensure all the people at-risk of an emerging threat are warned and people respond proactively to avoid failure of any one method to further reinforce the early warning messages. Early warning messages are disseminated using mobile telephones and Short Message Services (SMS) at the community level and using local media at the wider level (Smith et al. 2017). However, in rural areas community based organisations and community leaders need to be involved in disseminating early warning messages, since people may not have access to TV, radio or telephones. For example, in Sri Lanka, only 37% of 15–65 aged populations own a smartphone, while 22% do not have a phone (Galpaya et al. 2020). Therefore, it is also important to use traditional mechanisms to avoid the failure of advanced technology based early warning dissemination, particularly to reach the last mile in rural areas, where there is lack of information, communication and technology (ICT) infrastructure.

The application of simple technology can reach to the wider community with the complementary use of existing traditional community based practices. Even when people have access to more general early warning messages through radio broadcasting (which is the most widely used dissemination channel in rural areas), locally available public addressing systems may still be needed to disseminate more specific and customised instructions for further actions such as evacuation locations, routes, and other response related details. Figure 1 shows the most commonly used early warning dissemination methods in each stage of communication: from national operation centre to sub-national level (district and DS[1]), from sub-national

[1] DS stands for Divisional Secretariat Division in Sri Lanka, which is the mid-level state administration in the sub-national level (i. e. districts).

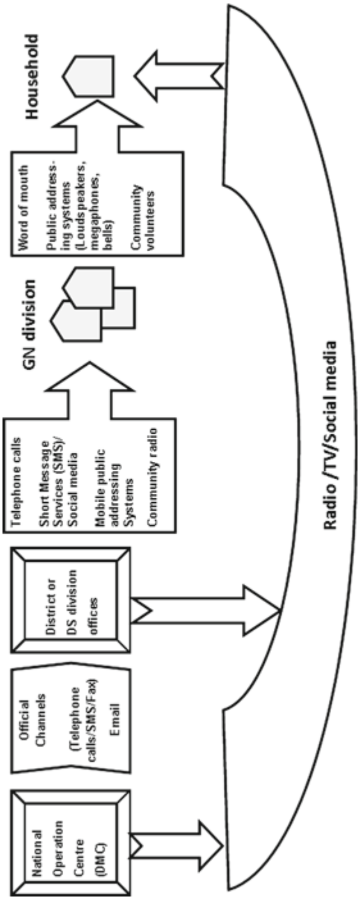

Fig. 1 Most common existing early warning message dissemination method in Sri Lanka

level to community level (GN[2] division), from community level to each household. The strong linkages between each level and multiple communication channels are the key factors for successful dissemination of early warning messages (Dutta & Basnayake, 2018; Haigh et al., 2020).

2.2 Role of Religious Places in Disaster Early Warning Dissemination

The local knowledge and existing information dissemination methods at the community level become highly relevant for a population with limited ICT infrastructure (Baudoin et al., 2016). The content of the early warning messages given to people at-risk should express the specific nature of an emerging risks, its potential impacts and contextualised to the specific geographic conditions and the needs of the areas under risk (Perera et al., 2020). Hence, the utilisation of community networks and local systems, such as religious places and community based organisations are critical in disseminating early warning messages to the people at-risk.

Further, megaphones, bells or messengers going from house to house are used as early warning dissemination channels at the community level. The key issue in the early warning dissemination equipment such as mega phone that was assigned for the use in disaster situations is the regular maintenance and testing of those equipment and their accessories. On the other hand, the equipment in the religious places are maintained well and tested frequently, since it is used very frequently, mostly every day. Hence, relying only on mobile public addressing equipment that are assigned for use in disaster situation has higher risk of failure of operation due to lack of proper maintenance than the use of loudspeakers in religious places, which are mostly in working conditions due to their frequent usage. However, use of megaphones become inevitable when the public addressing system in the religious places that have limited coverage of transmission. Above all these concerns, the level of trust with the early warning dissemination nodes play a key role in making people believe the contents of the message to act proactively according to the given procedures for timely preparedness and evacuation.

[2] GN stands for Grama Niladhari Division in Sri Lanka, which is the lowest administrative level in Sri Lanka (DS includes many GN administrative divisions).

3 Study Method

3.1 Study Locations

This study was conducted in 24 GN divisions (villages) in six DS divisions of three districts in Northern and Southern Provinces of Sri Lanka (Fig. 2). These locations were selected as they were part of a European Commission funded Disaster Preparedness (DIPECHO) in 2016–17.

These GN divisions belong to three project districts, namely Mannar and Killinochchi in the Northern Province and Batticaloa district in the Eastern Province. These three districts were selected for the implementation of the DIPECHO project by the DRR consortium partners based on their highest vulnerability and impact due to frequent disasters such as floods. Annual monsoon flood, mini cyclone (/high wind) and wild life animal attacks are the main frequent hazards that were prioritised by the village people during the consultations in the study locations. In order to assess the reliability of the public addressing systems in the religious and public

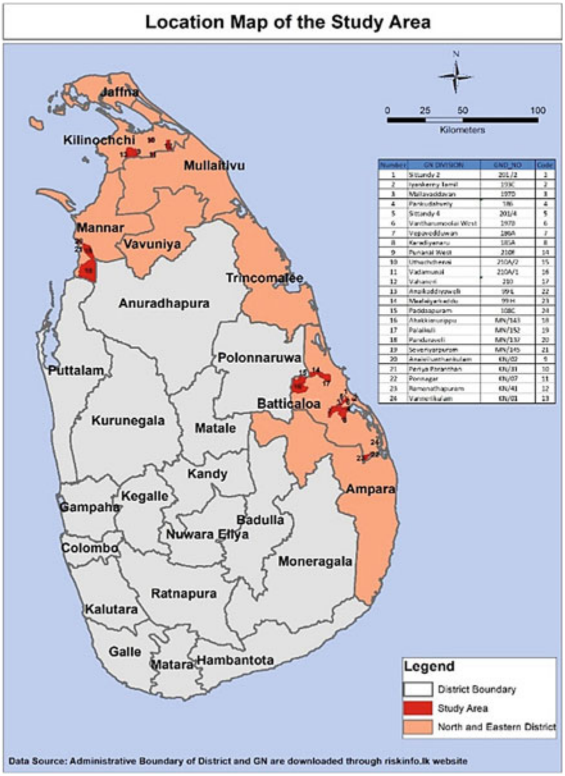

Fig. 2 Study loactions (GN divisions) in Sri Lanka map

places, 44 religious places were selected in the same 24 GN divisions. These include: (a) Temples—22, (b) Mosques—08, (c) Churches—01, and (d) 13 other locations.

3.2 Data Collection and Analysis

Data for this study was collected primarily during the field visit to the selected locations. Initially, a consultative meeting was conducted by the study team with the district and divisional disaster management officers to demarcate the locations. In the next step, a Focus Group Discussion (FGD) was conducted with GN (Village) Level Early Warning Committee members. In each of the GN, a GN Disaster Management Committee (GNDMC) was already formed by the District/Divisional Disaster Management Centre. Each GNDMC has different sub-committees including a Disaster Early Warning sub-committee. Since the focus of this study is to identify existing early warning dissemination mechanisms at the community level, this study adopted FGD method to interview the members of the early warning committee, who have more knowledge and experience in early warning systems and dissemination mechanisms.

At the start of FGD, the locations that have early warning systems were demarcated in the exisiting hazard maps which were already prepared for each GN by the District DMC. Further, the participants of FGDs were interviewed about the details of each early warning system that they are aware of, as to the existing early warning mechanisms, their coverage, available early warning equipment and their working conditions, problems faced in early warning dissemination and suggestions for their improvements.

After the end of FGD, a field visit to the early warning sites (includes religious places and other public places) in each GN division was conducted with the team of technicians who had technical expertise in public addressing system. The technical expert team assessed each of the public addressing system for several technical factors including the completeness of the set of equipment, quality of equipment, amplifiable reach of the equipment, appropriateness of the mounted locations and heights, safety of the instruments and wiring, and their current working conditions.

Data obtained from the focus group discussions and field study were analysed mainly using the content analysis of text data from the transcript records. The text analysis cloud was created from the transcripts of focus group discussion with early warning committee members in the study area. Further, some findings were drawn from the technical assessment report of the public addressing equipment by the team of technical experts.

4 Findings

4.1 Existing Early Warning Methods

The most common informal method of early warning dissemination among the village members is 'word of mouth'. However, this study showed that the early warning messages are primarily disseminated through phone calls, loudspeakers, fire crackers, bells, and megaphones. Three key stakeholders engaged in early warning dissemination are Grama Niladhari (GN), Rural Development Societies (RDS) and religious places such as Kovils (Hindu temples), Mosques and Churches. Some village leaders such as the Chief Trustee of the religious places or Presidents of the Rural Development Societies maintain regular contact with the irrigation department and District Disaster Management Unit to receive early warning information.

The Grama Niladhari (GN) who is the village administrator for the government informs to the President of the RDS and RDS communicate the message through the loudspeakers in religious places and using megaphones available with Village Early Warning Sub Committee. People also use firecrackers mainly when there is a risk of attack from wild animals (Elephants). When there is no loudspeakers or megaphones, bells in the temples are used to alert people about the imminent risk. It was also found that bells, shouting and using firecrackers have been indigenous practices for early warning carried over by certain communities to date mostly in the rural villages and sporadic human settlements. Loud speakers were available in 26 locations and temple/church bell was available in eight locations.

4.2 Effective Use of Early Warning Equipment

4.2.1 Types of Mounting for Loudspeakers for Public Addressing

A loudspeaker system was found as a public addressing system in 26 locations among the 44 public and religious locations inspected. It was found that the loudspeakers were mounted in trees in half of the locations assessed. Further, it was mounted on a wall or in an early warning tower in four locations each and in remaining locations either on a pole or on top of a building roof (Table 1).

Some of the pictures of mounting the loudspeakers taken in different locations, such as temples, mosques, and public places are shown in Fig. 3. It was assessed that only in eight locations (25% of the 26 locations), the loudspeakers were mounted in appropriate positions that can provide optimum reach to the target population (good coverage).

Table 1 Type of mount for loudspeakers and number of locations

Mount for loudspeakers	Locations
Early warning tower	04
Mounted in roof top	03
Mounted on a wall	04
Mounted in a tree	12
Mounted in a pole	02
Total locations	26/44

Fig. 3 Pictures of mounting loudspeakers in religious places

4.2.2 Access to electric power

All the religious places have access to electricity directly from the grid connection. However, 23 locations (of 26 assessed) have access to electric power directly from the national grid. The battery power source is used in the remaining three locations. Only one location has a generator as a source of power backup when there is power cut from the national grid. The other public addressing systems that existed with communities or village disaster management committees were either dependent on batteries or used with mobile power sources during the emergency situations such as power from three-wheelers and household batteries. The loudspeakers dependent on the battery were not immediate operational due to non-periodical maintenance of batteries.

4.2.3 Other Early Warning Equipment/Accessories

At least one mega phone was available in 16 locations out of 24 GN divisions (villages) assessed in this study. In most of the locations, the Megaphones and other early warning equipment were kept at Grama Niladhari's office by default, who is the leader of the GN level Disaster management Committee. However, the study found that most often during the emergency time, the access to those equipment was limited as the GN officer is not from the village or does not stay in the village. 60% of the equipment were immediately operational, while others were not due to lack of maintenance and availability of battery.

4.3 Early Warning Committees at the GN Level

More than 90% of the GN level Early Warning (EW) sub-committees consisted five to seven members, mostly leaders from active community based organisations such as Rural Development Society and Youth Groups. These EW sub-committee meetings are very ad-hoc and on demand basis prior to or during an emergency. Proactive regular meetings and assessing the hazard and early warning messaging was not observed. The role of religious organisation in the early warning committees was discussed in the Focus Group Discussions. The important role of religious organisations in early warning was acknowledged, however in majority of the early warning committees, there were no representations for religious organisations or religious leaders. The existence of multiple religious' organisations in a village and more often the competition and conflict in selection of members was highlighted as one of the limitations for religious organisations to get membership in the early warning committees.

4.4 Problems in Existing Early Warning Dissemination Mechanisms

- Early warning reachability:
  The early warning messages are mainly transmitted through audio/visual channels such as Televisions and Radio. This study highlighted that early warning messages do not reach the people who live in isolated housing schemes without access to electronic media. It was also found that houses are scattered within a village and they are far from the centre of the village. User friendliness of (literacy, decoding/understanding) early warning messages is another key concern. It was found that early warning messages sent via SMS and available in the internet of Disaster Management Centre or Meteorology Department were not accessible or understood by rural communities due to its format and language.

- Trustworthiness of early warning:
  The study found that when people receive multiple early warning messages through different sources which are sometimes mutually exclusive, there have been mistrust, which finally resulted in failure of properly reacting to early warning. This situation was highlighted in many of the FGDs and respondents recognised multiple instances, where they had acted on false or non-verified information. These situations have led to a confusion to react to early warning messages properly and resulted in unnecessary panic among the communities especially with regard to Tsunami early warning dissemination.
- Incompleteness in early warning messaging and management:
  The respondents receive only information but no proper instruction on action and in field follow-up. This happens when they only receive TV messages and which is not coordinated through a local action by the GNDMC or GN. The incompleteness of early warning messaging cycle with the feedback and follow-up is found as a gap in effectively improving and operationalizing the early warning in the study locations.

5 Discussion

The following recommendations were drawn from this study to increase the effectiveness of the existing early warning dissemination methods:

(a) Early warning needs to be translated to an early reaction with the blend of trust, clarity and increased lead time. In the study context, it was clear that the three aspects highlighted above were crucial and contributed to a large extent to make an early warning dissemination to the last mile effective. In many instances, the trust was the critical element and confusion had led to lessen the potential lead time to act. Religious organisations represented through their leaders have been a crucial trusted source of information. Hence, this study recommends to capitalise the trust with religious organisations and existing traditional mechanisms for effective early warning dissemination. It is important to proactively engage religious organisations in the community level early warning mechanisms, since they the capacity to mobilise resources, maintain the assets (early warning systems) and can reach the last mile effectively to save lives.

(b) The use of already existing places with public addressing systems need to be prioritised such as religious places as early warning dissemination nodes and technical reliability of the existing public addressing systems in religious and public places can be improved. The role of religious organisations in different phases of post-disaster management such as relief, recovery, rehabilitation and reconstruction, is widely recognised, yet the studies assessing the contribution of religious organisations and places in pre-disaster management phase including early warning dissemination and evacuation is limited (Adiyoso & Kanegae, 2013).

In general, religious institutions were able to engage in a variety of relief activities during and aftermath of a humanitarian crisis such as distributing food and non-food items, restoring education, and sheltering displaced people in religious centres, due to the nature of religious institutions in terms of their knowledge of the constituency they serve, long term presence within local populations, and standing as a trusted partner within these communities. However, the lack of integration of religious institutions and faith-based organizations in the pre-disaster management process at national and local levels often leads to ineffectiveness in the outcomes, when they become part of the implementation system in most of the faith-oriented communities during the emergence of a disaster.

(c) The religious and public places that have an already existing public addressing facilities need to be mapped to ensure adequate coverage of early warning dissemination through the existing public addressing methods. For example in Indonesia, religious entities actively engage in disaster risk communication during religious congregations and disseminating early warning messages through loudspeakers in mosques which can give a coverage to large number of neighbourhoods (Mulyasari & Shaw, 2017). Most often, any part of the village can be covered by a minimum of one public addressing system in the religious places. Hence, the inclusion of the population coverage of the public addressing systems for each of the religious places in the preparation of the village level risk maps.

(d) The criteria proposed to prioritise in selecting villages to install or enhance early warning dissemination mechanisms include: exposure to multi-hazards (identified using risk maps), lack of early warning dissemination mechanism available, large distance between two villages or higher number of isolated housing schemes/dispersed houses and, difficulty in accessing evacuation centres.

(e) As a minimum, one member of the religious and public places with the existing public addressing systems need to be part of the Early Warning Sub-Committee at the village level. The state authorities such as divisional disaster management centre can authorise these places as an early warning nodes, after extensive training and capacity building of their key members.

6 Conclusions

The early warning audit conducted in this study revealed that more than 90% of the villages have early warning committees established with 5–7 members. The 'word of mouth' between community members has been the most common warning dissemination strategy of the early warning message received from the early warning committee through divisional secretariat or government departments such as irrigation and agrarian departments, when there is enough lead time. The assessment of early warning devices at the religious and public places found that the installation of loudspeakers as the public addressing system was not effective in more than 75%

of the locations, in terms of their position, coverage, and technical sustainability. However, most of the villages (16 of 24 villages) have access to a megaphone as an early warning dissemination device, which is the easy-to-use technology by the early warning committee members, who were also trained to use it during the early warning phase of an emergency.

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Assessing Flood Risks in Malwathu Oya River Basin in Northern Sri Lanka for Establishing Effective Early Warning System

Nandana Mahakumarage, Vajira Hettige, Sunil Jayaweera, and Buddika Hapuarachchi

Abstract Recurrent (The views expressed herein are those of the author(s) and do not necessarily reflect the views of the United Nations Development Programme) flood events in 2016 and 2017 in Sri Lanka caused significant destruction, with damages and losses estimated at LKR 170 billion. Post Disaster Needs Assessment 2016 highlighted a series of shortfalls in disaster risk management in Sri Lanka, including absence of effective early warning systems. A major barrier for establishing an effective early warning system, is the lack of risk assessments, especially for floods. While many attempts were made to assess flood risk, none has progressed beyond mapping flood prone areas. Lack of a scientifically conceptualized and practically tested methodology for risk assessment, and data gaps has resulted in unavailability of risk assessments. A methodology, based on participatory techniques and GIS tools, tested at pilot scale in Southern Sri Lanka, was adopted for a basin-wide flood risk assessment in Malwathu Oya river basin. Under this, flood risk of 7790 households in Malwathu Oya river basin was assessed at the individual household level and validated using GIS tools and participatory methodologies. Results suggest that individual household level flood risk assessment is possible with available data and thus, targeted early warning systems can be established for communities-at-risk.

Keywords Early warning · GIS · Flood risk · Flood risk assessment

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1 Introduction

Globally, floods are the most frequent natural disaster, while its impacts are at varying degrees, with a few households to entire regions (Askman et al., 2018). Similar to the global situation, floods are the most common natural hazard in Sri Lanka. Of the 31,063 disasters reported in the country since 1974, 28% are related to floods. During the same period, floods are responsible for 55% of all disaster related house damages (Desinventar.lk). Therefore, it is not just a frequent disaster, the country experienced annually, but its impacts are devastated to the communities as well as the country's economy. In terms of human mortalities, the floods related deaths in the island nations is accounted for 5% of all disaster related mortalities in the country, since 1974. When the 2004 Indian Ocean Tsunami is excluded, the situation is alarming and 34% of the all disaster related deaths are related to floods.

According to UNDRR and ADPC (2019), hydro-meteorological disasters, including floods are on the increase in Sri Lanka. At the same time, the number of people affected due to floods is also on the rise, largely because of climate induced rainfall variability, population growth, and unplanned development activities, which expose more people to flood risks. Figure 1 shows the flood affected people in the country since 1974.

Sri Lanka's climate vulnerability is repeatedly revealed in global indices. According to Global Climate Risk Index, the country is among the first 10 climate risk vulnerable countries in 2018, 2019, and 2020. The Index ranked Sri Lanka at second place amongst climate related disaster affected countries in the world for 2019 (Eckstein et al., 2019). Climate change induced extreme weather events and climate variability has increased the country's flood vulnerability. The country has 103 major river basins, of which 25 are considered to be highly vulnerable for floods (Department of Irrigation,). Even though the most parts of the country are fallen within a river basin, rainfall anomalies have caused not just repeated cycles of flood, but drought as well, compromising development gains of the country. According to the World Bank (Global Facility for Disaster Reduction, 2020), flood related damages and losses of

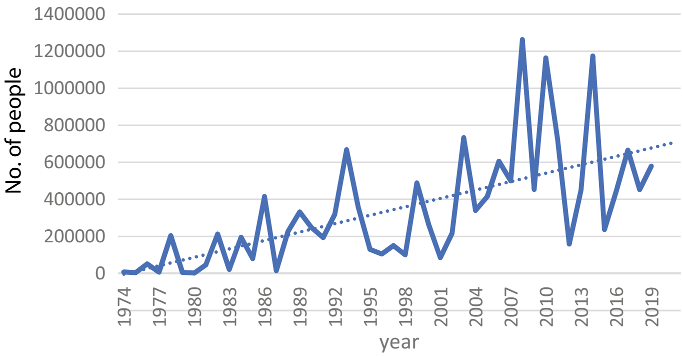

Fig. 1 Flood affected people in Sri Lanka from 1974–2020 (*Source* Desinventar.lk)

the country can be as much as US$380 million annually. In 2016, the Ministry of Disaster Management and the Ministry of National Policies and Economic Affairs (2016), in collaboration with the European Union, UNDP, and the World Bank carried out detailed Post Disaster Needs Assessments to assess the flood related damages and losses and also to estimate the recovery needs of the country. These assessments, in addition to provide estimation on damages, losses and recovery needs, also highlighted a series of shortfalls in the disaster risk management in Sri Lanka, which includes last mile early warning dissemination, and disaster response at local level among others.

Lack of disaster risk assessment has been a major barrier for establishing an effective early warning system, especially for floods. While many attempts were made to develop flood risk assessments, none has progressed beyond mapping the flood prone areas. Lack of scientifically conceptualized and practically tested methodology to assess flood risks and data gaps made such efforts fall short of expected results. Moreover, lack of clarity about the elements of disaster risk is also limiting the opportunity of conducting full scale disaster risk reductions, especially for floods.

2 Disaster, Disaster Risk and Disaster Risk Assessment

According to UNDRR Terminology (2020), disasters are a “serious disruption of the functioning of a community or a society at any scale due to hazardous events interacting with conditions of exposure, vulnerability and capacity, leading to one or more of the following: human, material, economic and environmental losses and impacts”. UNDRR defines disaster risk as probabilistic determination of potential loss or damage to a society, community or a system in a specific time period. Therefore, effective disaster risk assessment depends on the understanding of such hazardous events and conditions of exposure, vulnerability and capacity.

Interconnection between the above conditions or concepts are conceptualized by Blaikie et al. (1994 in Hapuarachchi, 2014, p. 06). They presented risk, hazard and vulnerability in a pseudo-equation as: $R = H \times V$, where; $R =$ Risk [Disaster Risk], $H =$ Hazards, and $V =$ Vulnerability. Similar linkages with different combinations of elements were proposed later in IPCC Fourth Assessment Report, IPCC Fifth Assessment Report and World Risk Index. A close review of these formula suggests that all these have same logical argument and are extensions of the formula presented by Blaikie et al. (1994).

According to UNDRR (2020), hazard can be defined as a process or phenomena that may cause loss and damage to biophysical environment. The potential damage of a hazard is linked to its magnitude and frequency. However, in assessing disaster risk, exposure is interchangeably used for hazard and instead of magnitude and frequency of hazard, exposure of people, assets and infrastructure to such hazards is assessed (Bündnis Entwicklung Hilft & Ruhr University Bochum, 2019). In this study, frequency and magnitude of hazard is considered as important elements to assess potential damage.

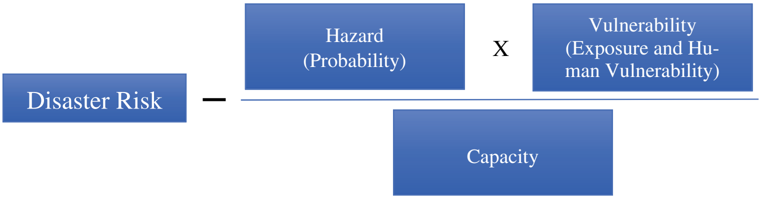

Fig. 2 Interconnected nature of disaster risk, hazard, vulnerability and capacity

The term vulnerability has as many as 30 different definitions (Birkmann, 2013). UNDRR Terminology (2020) defines the vulnerability as "[the] conditions determined by physical, social, economic and environmental factors or processes which increase the susceptibility of an individual, a community, assets or systems to the impacts of hazards". IPCC's Fourth Assessment Report (IPCC, 2007, p. 883) described the exposure as one of key elements of vulnerability along with sensitivity and adaptive capacity, while Alcántara-Ayala (2002) discusses on natural vulnerability, in addition to the human vulnerability, which is characterized by the geographical location in which people live. In line with these arguments, the study conceptualizes the exposure as one of the key components of vulnerability.

Capacity or adaptive capacity is discussed in many literature (UNDRR, 2020; IPCC, 2007, 2013; Birkmann, 2013), as one of the important elements that determines the disaster risk. It is the strengths, resources and ability of the community to manage and reduces disaster risks. Thus, the capacity can also be considered as the flipside of vulnerability, which is the conditions determined by physical, social, economic and environmental factors or processes which increase the resilience of a community to the impacts of hazards. However, in order to capture the specific adaptive capacity of the community to manage and reduces disaster risks, the study used capacity as a separate constituent of disaster risk.

Therefore, the study used:

In line with this formula (Fig. 2), a methodology was developed to assess the flood risk of the at-risk communities in Malwathu Oya river basin. This study areas covers lower Malwathu Oya areas which includes four flood vulnerable Divisional Secretariat (DS) Divisions in both Vavuniya and Mannar districts of Sri Lanka.

3 Study Area

Malwathu Oya is the second largest river (catchment area of 3284 km^2) with a length of 162 km. It originates from Ritigala Hills (766 m MSL) in the North Central Province and flows to the sea at Arippu in Mannar District (Sivakumar and Thiruvarudchelvan, 2019). Major part of the basin spreads over the Anuradhapura district in the upper catchment and further narrows and flows through Vavuniya and Mannar districts (Fig. 3). The Basin has a large number of small reservoirs (1450) in addition

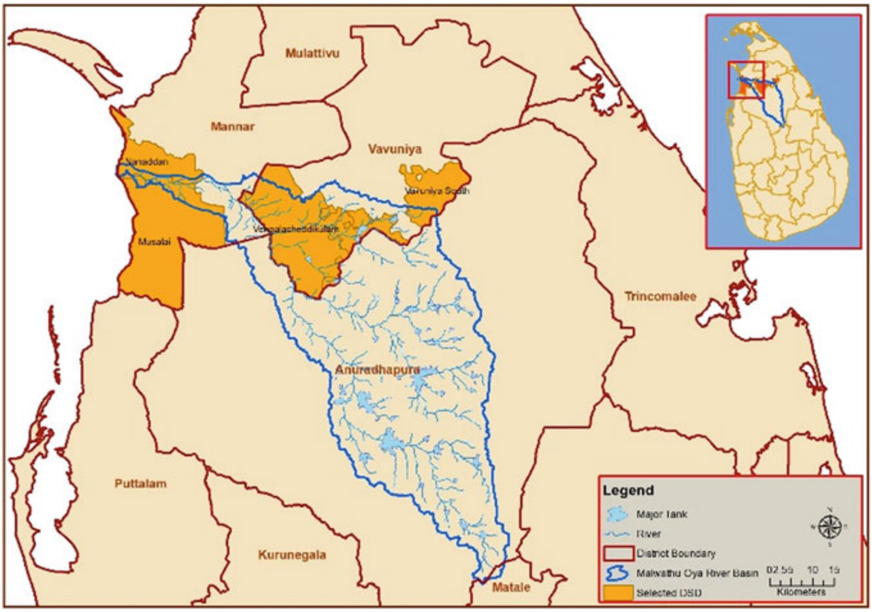

Fig. 3 Study area

to the five major reservoirs in the upper catchment. The total population in the basin is around 410,000, of which the majority are rural farmers. Poverty head count index in Anuradhapura, Vavuniya and Mannar districts are 7.6, 3.4 and 20.1 respectively (Department of Census and Statistics, 2012/13).

During the last decade, severe flood events have been recorded in Malwathu Oya basin in 2011, 2014 and 2016. A major flood event occurred in December 2014 is considered the worst since 1957, which resulted breaching of a number of small reservoirs, submerging a number of rural villages in downstream districts of Vavuniya and Mannar (Meegastenna, 2019). The river basin does not have an operational and effective flood early warning system, which provides a flood warning to the at-risk households with sufficient lead time. The Department of Irrigation, under the World Bank funding is conducting a basin-wide study, which is expected to develop a hydro-meteorological observation system and flood model (Kumari et al., 2019). This study will augment the current initiatives of the Department of Irrigation by providing comprehensive flood risk assessment. Figure 3 shows the Study area.

4 Methodology

Even though, there had been any attempts to conduct flood risk assessment in Sri Lanka, none has provided comprehensive risk assessment to establish a targeted early warning system. A methodology based on participatory techniques and GIS tools tested in Ambalantota, in Southern Sri Lanka provided an approach for risk assessment at individual household level (Mahakumarage et al., 2012), but it had been tested for a small area. The objective of this flood risk assessment was to strengthen the Flood Early warning system in the Malwathu Oya River basin. The flood risk data collected by this study will be fed into the flood models and early warning systems of the Malwathu Oya basin of which generate real time location specific warning messages for early response.

Since the local vulnerability and capacity for flood is heavily dependent on the geo physical and socio economical characteristics of the particular locality, accurate reflection of ground realities by the survey data set is vital. Household data collected in the flood affected Grama Niladhari (GN) Divisions (lowest tier of the administrative set up in Sri Lanka) mainly used for analysis. In addition, GN and Divisional Secretariats (DS) division level data has been incorporated for analysis.

Sequence of the activities conducted can be listed down as follows.

1. National and District level planning meeting—These planning meetings conducted to orient the key stakeholders and consult them on the methodology of the data collection process.
2. Identification and verification of flood prone GN divisions in Vavuniya and Mannar districts based on Desinventar.lk database. These were validated with the data available at district and DS division level.
3. Mapping the building footprint of the basin (using the Open Street apping software). The digitizing scale was 1:2000. All buildings in the flood affected GN divisions were digitized as polygons to enable calculation of the floor area of the buildings. Existing road networks, water bodies, public buildings and other points of interest were also marked.
4. GN level base maps were prepared to facilitate household survey. These base maps consisted of GN boundary, buildings, road names, water bodies, public buildings with the support of the communities.
5. Household survey was conducted using a pre-determined questionnaire, which covers the variables for vulnerability and capacity assessment. Each household was given a unique identification number to link the database into the map.
6. Flood inundation area mapping—As the satellite images were not available, flood inundation areas were mapped using both participatory mapping tools and GIS techniques. Participatory tools were used to mark 2014 flood layer. Digital Elevation Model (DEM) was prepared interpolating the 1 m contour of the area to differentiate riverine floods from local floods.
7. Household database development—An excel database was prepared by tabulating the household data collected in each of the GNDs.
8. The household database was linked to this digitized housing layer via unique identification number given to each household.
9. Validation meetings were conducted in each DS division to validate the features of the maps.
10. Flood risk assessment—Household data, GN and DS level data and flood inundation data collected by the survey was used to assess the flood risk.

Main steps in risk calculation and mapping

This section explains the variable used and data normalization, weighting and application of risk formula to calculate risk levels.

(a) Variable identification
Hazard—2014 flood was considered as the main flood event that used to identify the flood prone areas. Frequency analysis was carried out by using the data related to flood events since 1974.
Exposure—At-risk households in the flood prone areas considered and degree of flood exposure was also assessed based on the flood inundation levels.
Vulnerability and Capacity—Tables 1 and 2 lists the variables used for vulnerability and capacity assessment of the at-risk households. Data relevant to

Table 1 Variables used for vulnerability assessment

Variable	Rank				Weightage (%)
	0	1	2	3	
Total number of members of the household	1–2	3–4	5–6	7 or more	10
Number of female members	0	1–2	3–4	5 or more	5
Number of children under 5 years	0	1	2	3 or more	10
Number of people over 65 years	0	1	2 or more		10
Number of disabled members	0	1	2 or more		10
Number of members with special medical conditions	0	1	2 or more		10
Household poverty level	Above the poverty line	Below the poverty line			10
Number of dependents	0	1–2	3–4	5 or more	10
Number of unemployed adults (over 18)	0	1	2–3	4 or more	10
Number of people attended school up tograde 8	0	1	2–3	4 or more	5
Housing category	Permanent	Semi-permanent	Improvised material		10
Total					100

Table 2 Variables used for capacity assessment

Variable	Rank no				Weight (%)
	0	1	2	3	
Average annual income (Rs)	<200,000	200,000–350,000	350,000–500,000	>500,000	15
Family assets	0	1 or more			10
Drinking water source (access level for drinking water after disaster)	Agri well, river/oya/canal/stream/tank, filtered water (from outside source), other high vulnerable sources	Pumped water supply (private), dug well (private or neighboring), Tube well, Public well, Rain Water Harvesting system	Main water supply (NWSDB), community water supply		15
Type of toilets (availability of usable toilet after disaster)	No toilet, Septic tank, gullies and manholes	Separate toilet	Attached toilet with basic facilities and modern facilities		10
Number of floors of the house	1	2	3 or more		20
Ownership of the house	Illegal	Rented	Official residential	Own	5
Awareness on flood	No	Yes			5
Preparedness for flood	No	Yes			10
Availability of flood early warning system	No	Yes			10
Total					100

these variables were collected through a household survey commissioned in 28 floods prone GN divisions (7790 households).

(b) Data normalization

Data normalization was done, since different data sets were used for the analysis. Collected data was rescaled into 0–1 scale for data analysis. Following formula was used for the data normalization.

With positive relationship;

$\text{Index} = \frac{\text{Actual value} - \text{Minimum value}}{\text{Maximum value} - \text{Minimum value}}$

With negative relationship;

$\text{Index} = 1 - \frac{\text{Actual value} - \text{Minimum value}}{\text{Maximum value} - \text{Minimum value}}$

(c) Assigning weights to variables

Weights were assigned to the variables identified for vulnerability and capacity assessment in consultation with sector experts and key stakeholders. In addition, a ranking method was also used to rank the variables. Tables 1 and 2 shows the rank values and weightages given for each variable. Weightages can be changed using statistical methods or sector expert judgment, based on the requirement.

(d) Hazard, exposure, vulnerability, capacity and risk index calculation

An Excel based programme was developed to calculate the "Risk" value of each household unit. This program combined data collected by the household survey and mapping. The Excel program includes:

- Data feeding
- Data normalizing
- Data weighting (user can change the weight of the variables)
- Hazard, exposure, vulnerability and capacity index calculating
- Risk index calculation
- Direct linking ability with GIS.

This Excel based program is one of the major outputs of the study, which will be available for the stakeholder agencies for decision making. The programme enables the different sectors to carryout risk calculation, selecting the sector specific variables and appropriate weightages.

(e) Reflect the risk values in the GN level GIS maps (Link vulnerability and capacity data base into the risk map).

5 Result and Discussion

1. Profile of the study area: Flood prone area mapping taking the 2014 flood layer as the baseline, included 7790 houses scattered in 465 km^2 land area of 28 flood affected GN Divisions belonging to the four DS divisions. Table 3 shows detail of the study area.

2. Mapping results: hazard proneness, vulnerability, capacity and overall risk level of individual households are now available for both Mannar and Vavuniya

Table 3 Building and land area statistics of the study area

District	DS division	GN area (km^2)	Houses	No. of public building	Total buildings
Vavuniya	Vengalacheddikulam	244.6	4350	174	4524
	Vavuniya South	21.78	835	36	871
Mannar	Nanattan	77.23	2169	75	2244
	Musalai	121.82	436	13	449
Total		465.43	7790	298	8088

districts, which can be used for disaster preparedness and response. These maps show field situation at maximum ground zooming level. Figure 3 shows flood affected area in Kiristhavakulam GN Divisions in Vengalacheddikulam DS division in Vavuniya District, illustrating vulnerability, capacity and risk levels of individual households.

3. Analysis of data suggests that even though 7790 houses are in the flood prone areas in Vavuniya and Mannar districts are exposed to riverine floods in Malwathu Oya, only 22 houses are falling into the category of high-risk households. The data also suggests that safe evacuation of 1933 households with high and moderate flood exposure shall be carried out prior to a flood event, the disaster management authorities shall require to provide more attention to 117 households, whose flood risk is either high or moderate (Table 4).
4. Table 4 also shows that 75.2% families are expose to low to very low level of floods whereas 85.9% of the families show low to very low level of flood vulnerability. In contrast, 76.9% families have high to moderate capacity to face the floods. Therefore, only 3% of the families are identified as high risk vulnerable families.
5. The housing layer is linked to a database with household level information, including contact numbers, details of members of the households those require special attention before, during and after an emergency situation.
6. Figure 4 shows how the exposure, vulnerability, capacity and overall risk values change in selected households in Kiristhavakulam GN Divisions in Vengalacheddikulam DS division in Vavuniya District. This reveals that even

Table 4 Flood exposure

Risk component	Number of houses				Total	Percentage				Total
	High	Mod	Low	Very low		High	Mod	Low	Very low	
Exposure	663	1270	981	4876	7790	8.5	16.3	12.6	62.6	100
Vulnerability	97	1004	3783	2906	7790	1.2	12.9	48.6	37.3	100
Capacity	380	5597	1621	192	7790	4.9	71.8	20.8	2.5	100
Risk level	22	95	838	6835	7790	0.3	1.2	10.8	87.7	100

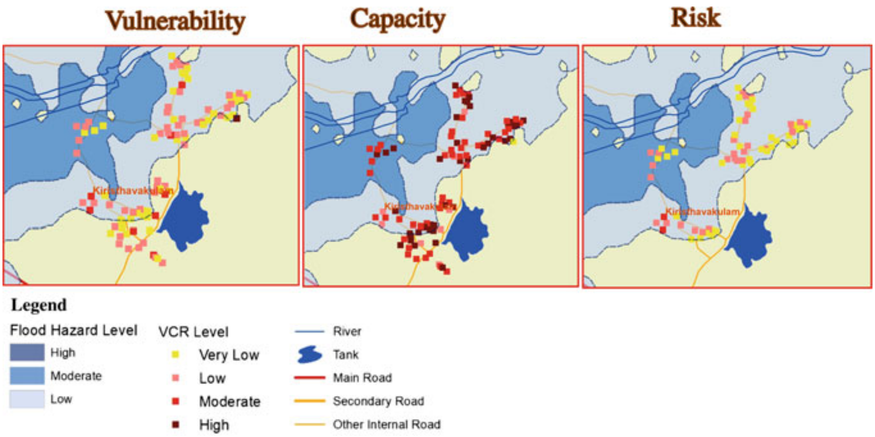

Fig. 4 Vulnerability, capacity and risk levels of the households in Kiristhavakulam GN divisions in Vengalacheddikulam DS division in Vavuniya district

though the houses are equally exposed to flood hazards, their overall risk levels differ from one household to other based on their specific vulnerabilities and capacities to flood events.

7. Weightages given for the criteria usedfor vulnerability and capacity assessment can be set based on the realistic estimates or expert judgement in consultation with relevant experts.
8. All public buildings and road network also mapped for each and every GN divisions in the two districts, thus safe evacuation routes and Safety Centres can also be identified and used for disaster preparedness and response activities.
9. Specific vulnerability and capacities of individual households can be used for disaster response and recovery activities. Availability of full database on livelihood assets and housing type will facilitate the disaster management authorities to conduct damage and loss assessment quickly and easily.

6 Conclusion

The study provided a detailed data set and spatial location of 7790 households in Vavuniya and Mannar districts, including their flood exposure level, vulnerability, capacity and risk levels of individual households. These data and maps can be used to provide targeted early warning with a lead time once the flood model is run in the Malwathu Oya river basin. Results suggest that individual household level flood risk assessment is possible with available data and thus, targeted early warning systems can be established for communities-at-risk.

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Study on Landslide Early Warning by Using Rainfall Indices in Sri Lanka

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Abstract Japan International Cooperation Agency (JICA) and National Building Research Organisation (NBRO) have been conducting projects to prevent and minimize landslide damages. Landslide early warning is one of the targets of the JICA-NBRO projects based on the analysis of rainfall indices. The analysis of these indices, such as working rainfall and Soil Water Index (SWI), was carried out. The Soil Water Index is an output of conceptual hydrological model representing soil water content. Time series of observed rainfall at 25 gauging stations from 2014 to 2020 were utilized to calculate rainfall indices. Moreover, past landslide records were utilized to analyze the correlation between landslide occurrences and the calculated rainfall indices. Results showed that most of the past landslides were caused by severe rainfall events in which Soil Water Index exceeded 112. Results also showed that small-scale slope failures were caused by relatively minor rainfall events. The critical values of rainfall indices causing landslides depend on the regional characteristics. The critical value in the south-western region tends to be higher than in the northern and southern regions. It seems that the higher rainfall in the south-western region increases the critical rainfall value of landslide occurrence. There is a possibility to improve the accuracy of landslide early warning by using the rainfall indices considering regional characteristics.

Keywords Landslides · Early warning · Soil water index

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1 Introduction

Sediment disasters including landslides, debris flows and slope failures cause severe social damages. According to JICA (2015) which summarize past disaster records of DesInventar, a disaster information management system, ca. 35% of death and missing by disasters were caused by landslides and other sediment disasters in Sri Lanka in the decade from 2007 to 2016. Most landslides in Sri Lanka were triggered by heavy rainfall in the mountainous region located in the center of Sri Lanka. The rapid infiltration of rainfall, causing soil saturation and a temporary rise in pore-water pressures, is generally believed to be the mechanism by which most shallow landslides are generated during storms (McColl, 2015; Wieczorek, 1996). Prediction of landslide risk triggered by heavy rainfall is important to reduce the disaster damages.

National governments facing landslide risks are implementing landslide forecasting and early warning in the world (Guzzetti et al., 2019). Various methodologies are proposed and applied on landslide early warnings. Direct and detailed observation of landslide mass movement is usually utilized for site specific warnings; whereas, rainfall indices are often applied for regional warnings since rainfall observation is easily applicable for wide-area warnings (Delfim et al., 2018; Guzzetti et al., 2019; Ramesh et al., 2009).

In Sri Lanka, National Building Research Organisation (NBRO) is the focal organisation implementing structural and non-structural countermeasures for landslides and other sediment disasters. NBRO issues landslide early warnings based on observed rainfall. There are previous studies (Bandara, 2008; Kumara et al., 2018; Rajapaksha et al., 2019) which reported correlation between rainfall and landslide occurrence in Sri Lanka. Three levels of rainfall thresholds on landslide warnings have been defined by Bandara (2008) based on empirical assessment of past landslide records in Sri Lanka. According to the previous study, NBRO issues landslide warnings when the observed 1-h or 24-h rainfall exceeds the warning thresholds. However, the warning thresholds are uniform and constant for the entire country. Therefore, in order to improve the accuracy of the warnings, it is required to revise the warning thresholds considering regional characteristics.

Japan International Cooperation Agency (JICA) and NBRO have been conducting projects to prevent landslide damages since 2014. In the on-going technical cooperation project between JICA and NBRO, titled "Project for Capacity Strengthening on Development of Non-structural Measures for Landslide Risk Reduction", one of the targets has been identified as the establishment of landslide early warning system based on analysis of rainfall indices due to the necessity of more accurate landslide early warning with site specific information. During the project implementation, analysis of rainfall indices was carried out. This study was done as part of the JICA-NBRO project.

The main objectives of this study are to clarify regional characteristics of rainfall with rainfall indices which triggered sediment disasters and to determine new critical lines of the landslide warnings in Sri Lanka.

2 Study Area and Method

2.1 *Study Area*

Figure 1 shows the study area and the locations of rainfall gauging stations. The study area is the central high land of Sri Lanka where high risk of landslides exists due to steep terrains and heavy rainfall occurrences (NBRO, 2020; JICA, 2015). Geology of southern, central and eastern parts of the study area is classified as “Highland Complex” consisting of migmatized pelitic gneisses with various mineral assemblages, which are intercalated with quartzites, mafic granulites and calc-silicate gneisses. Northwestern part of the study area is classified as “Wanni Complex” and “Kadugannawa Complex” consisting of Amphibolite-facies metapelites, mafic to intermediate gneisses, calc-silicate rocks, granitic gneisses and migmatites (Osanai et al., 2016).

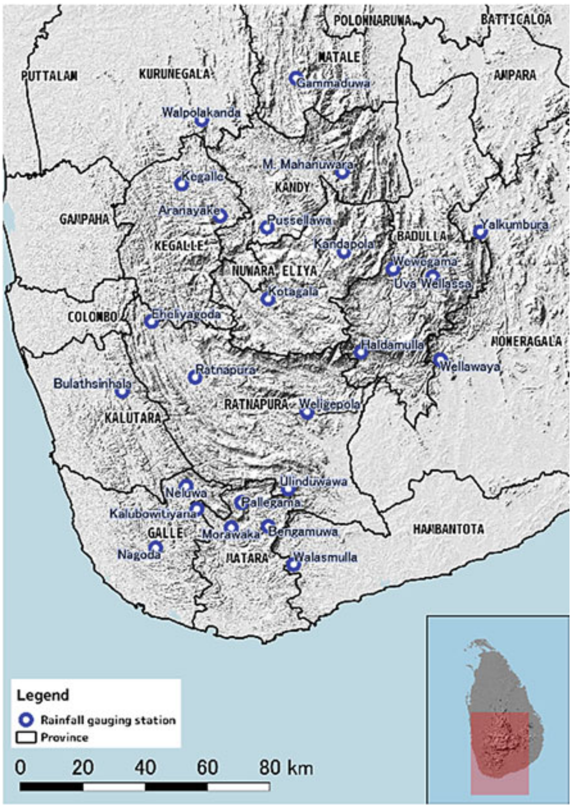

Fig. 1 Map of study area and locations of rainfall gauging stations

Mean annual rainfall in the western slopes of the highlands exceeds 4500 mm/year (Burt & Weerasinghe, 2014). Seasonal variation of rainfall is determined by the southwest monsoon (May–Sep.), northeast monsoon (Dec.–Feb.) and two inter-monsoon seasons. The highest mean monthly number of people affected by sediment disasters during the decade from 2007 to 2016 was recorded in May; the second peak of the mean monthly number of affected people was from October to January (JICA, 2015). It seems that seasonal rainfall by the southwest monsoon and tropical cyclones and convectional rainfall during the inter-monsoon periods triggered many landslides and other sediment disasters. Considering the rainfall pattern, regional characteristics of correlations between rainfall and landslides were analyzed in this study.

2.2 Rainfall Data and Gauging Stations

Time series of observed 30-min rainfall at 25 automatic rainfall gauging stations (Fig. 1) was collected and utilized for the analysis. Period of the rainfall analysis is up to a maximum of six years (from April 2014 to April 2020); mean period of the analysis is ca. four years due to lack of rainfall data. When rainfall records were missing during major disaster events, rainfall data were interpolated with observed rainfall data at surrounding gauging stations.

2.3 Landslide and Other Sediment Disaster Records

Records of past landslides and other sediment disasters, which occurred near the gauging stations from 2014 to 2019, were collected from NBRO investigation reports, DesInventar and other data sources. When information about the time of disaster occurrence was missing, it was assumed that the time of occurrence coincided with the time of rainfall peak on the day.

One Hundred Nineteen disaster records were selected and utilized on the analysis. Half of the disaster records concentrated on the three major rainfall events in December 2014, May 2016 and May 2017.

2.4 Method of Analysis

An empirical method was applied to analyze the correlation between landslide occurrence and triggering rainfall. 1.5 h half-period working rainfall (1.5 h WR) as a short-term rainfall index and Soil Water Index (SWI) as a long-term rainfall index were calculated by using the observed 30-min rainfall at each gauging station. The short term rainfall index (1.5 h WR) indicates effects of rapid increment of soil water amount near surface layer. On the other hand, the long term rainfall index (SWI) focuses on soil water infiltrating into deeper layers and effects of remaining soil water fed by past rainfall events. Both rainfall indices were developed to estimate increment of landslide risks (Okada et al., 2001).

The general formula of the working rainfall is as follows.

$$R_w = \sum_i 0.5^{i/T} R_i$$

where, R_w: Working rainfall (mm), R_i: Rainfall at time i (mm/h), i: Time step, T: Half period (h). The working rainfall increases when rainfall occurs, and falls to one-half of the initial amount by the half period (T) simulating percolation and discharge of soil water. In this study, the value of half period (T) was fixed as "1.5 h" based on the result of Rajapaksha et al. (2019).

Long term rainfall index, SWI, was developed by Okada et al. (2001) as an indicator of landslide risks and is utilized to issue landslide early warnings in Japan. SWI is calculated by using a tank model, a conceptual runoff model developed by Sugawara (1972). The tank model, consisting of surface, sub-surface and base flow tanks, simulates amount of water in soil layers and discharge (Fig. 2). Parameters of the tank model were proposed by Ishihara and Kobatake (1979) through runoff analysis in the pilot mountainous basins in Japan. These parameters are utilized for practical nationwide landslide warnings by Japanese government (Osanai et al., 2010) and were validated in Sri Lankan conditions by Rajapaksha et al. (2019).

The formula of SWI is as follows:

$$\mathrm{SWI} = S_1 + S_2 + S_3$$

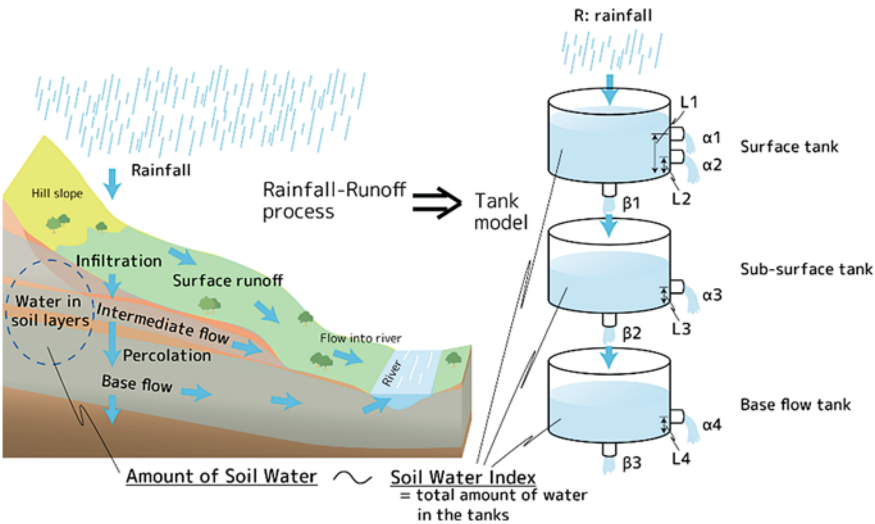

Fig. 2 Structure of tank model

$$S_1(t+\Delta t) = (1-\beta_1 \Delta t).S_1(t) - q_1(t).\Delta t + R$$

$$S_2(t+\Delta t) = (1-\beta_2 \Delta t).S_2(t) - q_2(t).\Delta t + \beta_1.S_1(t).\Delta t$$

$$S_3(t+\Delta t) = (1-\beta_3 \Delta t).S_3(t) - q_3(t).\Delta t + \beta_2.S_2(t).\Delta t$$

$$q_1(t) = \alpha_1[S_1(t) - L_1] + \alpha_2[S_1(t) - L_2]$$

$$q_2(t) = \alpha_3[S_2(t) - L_3]$$

$$q_3(t) = \alpha_4[S_3(t) - L_4]$$

where, S_1, S_2, S_3: Water amount in the tank (mm), $\beta_1, \beta_2, \beta_3$: Infiltration rate, q_1, q_2, q_3: Discharge (mm/Δt), Δt: Time step, R: rainfall (mm/Δt), $\alpha_1, \alpha_2, \alpha_3, \alpha_4$: Runoff ratio, L_1, L_2, L_3, L_4: Height of runoff hole (mm). 10-min time step (Δt) is utilized on this analysis. SWI is calculated as the total amount of simulated water in the tanks ($S_1 + S_2 + S_3$) at each time step.

The calculated 1.5 h WR and SWI time series and points of landslide occurrence were plotted together on snake curve charts and time series charts to identify correlations between landslide occurrence and triggering rainfall. The snake curve charts are scatter line charts with a short term rainfall index axis (Y axis) and a long term rainfall index axis (X axis).

In addition, the probability of rainfall occurrence was estimated. Gaussian function and logarithmic-Gaussian function were chosen for probability density functions of the long term rainfall index and the short term rainfall index, respectively. Both probability density functions were estimated based on the calculated 30-min interval rainfall indices and utilized to calculate equal probability lines. Equal probability lines were also plotted together on the snake curve charts.

Moreover, a rainfall critical line was determined as a boundary line of landslide occurrence and non-occurrence on the snake curve chart of each gauging station. The critical lines depend on regional characteristics of geology, topography, hydro-logy and meteorology (Nomura et al., 2014; Osanai et al., 2010).

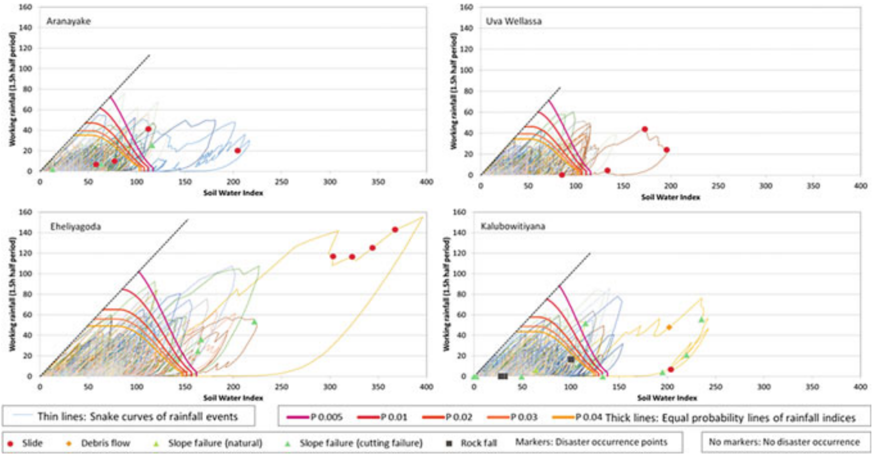

Fig. 3 Snake curve charts of representative gauging stations

3 Results and Discussion

3.1 Calculated Results of Short-Term and Long-Term Rainfall Indices

The calculated results of 1.5 h WR, SWI, equal rainfall probability lines and disaster records at four representative gauging stations are shown on the snake curve charts of Fig. 3. The four representative gauging stations are located in the northeastern, northwestern, southern and southwestern sub-area of the study area, respectively. The representative stations were selected because the longest rainfall time series data and plural landslide records are available at the representative stations.

Ten landslides of the total 13 landslides and one debris flow near the representative gauging stations were caused by heavy rainfall exceeding 112 SWI. The SWI values of rainfall events triggering landslides and debris flows were significantly higher than the SWI values that did not cause disasters. On the other hand, the slope failures, cutting failures and rock falls occurred even in the smaller rainfall events.

3.2 Discussion

3.2.1 Correlation Between Rainfall and Disaster Occurrence

The calculated results (Fig. 3) revealed that SWI, a long-term rainfall index, is a reasonable indicator of landslide and debris flow occurrences. When landslides and/or debris flow occurred, SWI was significantly high (ave. 162.7, std. 93.3). This value

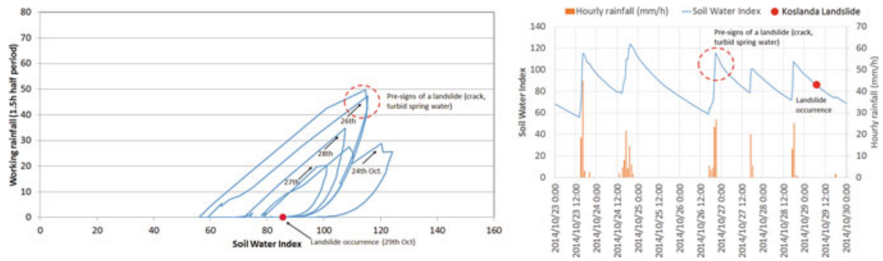

Fig. 4 Snake curve and rainfall time series charts of Koslanda landslide

corresponds to 99.7th percentile. 1.5 h WR, a short-term rainfall index, also tends to be high when landslides were caused (ave. 45.4, std. 42.9). However, both average and standard deviation of 1.5 h WR during landslide events were approximately equal because landslides also occurred even if 1.5 h WR was nearly zero. Hence, 1.5 h WR does not show a clear difference between landslide occurrence and non-occurrence compared with SWI. This result suggests that the long-term rainfall index is more significant and important than the short-term rainfall index since convective short duration rainfall commonly occurs in Sri Lanka; but, occurrence of long duration heavy rainfall is relatively rare.

Figure 4 shows a snake curve and rainfall time series charts of Koslanda landslide which occurred at 7:15 a.m. on the 29th of Oct. 2014. The SWI value at that time was 86, which is lower than the other landslides. According to Shimano et al. (2019), pre-signs of landslides, such as cracks and turbid spring water, were found on 26 Oct before the landslide occurrence. The peak of SWI on 26 Oct reached 110, which is a value equal to those for other landslides. The intermittent rainfall continued until 29 Oct and triggered the landslide. This case study suggests that landslides occur even if rainfall indices are low because it takes time for rainwater to infiltrate into the deeper landslide surface and to cause a soil-mass movement. Therefore, it is difficult to predict deep-seated landslides based on rainfall analysis alone. Pre-signs of landslides are important for the prediction of deep-seated landslides.

3.2.2 Critical Lines of Disaster Occurrence

As shown in Fig. 3, the equal probability lines ($p = 0.005$) of 30-min interval SWI and 1.5 h WR tend to show the boundary of landslide occurrence and non-occurrence. This result signifies that there is a possibility that the equal probability lines ($p = 0.005$) can be used as the rainfall critical lines of the landslide early warnings.

Thus, ratios of successful predictions, miss-shots and air-shots of early warnings were estimated by presuming equal probability lines ($p = 0.005$) as critical lines. 119 disaster records and rainfall data at 25 gauging stations in the study area were utilized for this analysis. As a result, 73% of landslides and debris flows were predicted by using the critical lines; another 27% of the landslides and debris occurred under

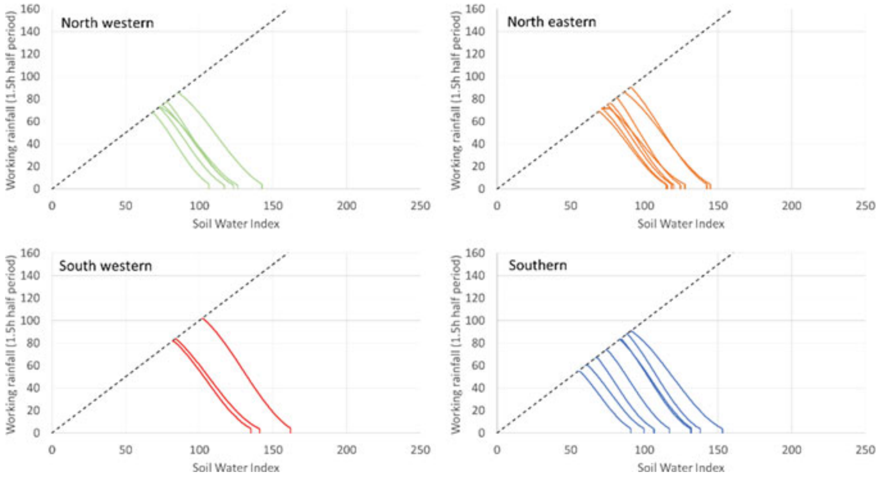

Fig. 5 Equal probability lines

the critical lines (miss-shots). On the other hand, the successful prediction ratio of slope failures, cutting failures and rock falls is low (38%). This result indicates the difficulty of predicting small-scale slope failures, cutting failures and rock falls by using SWI and 1.5 h WR.

The air-shot ratio, which means rainfall indices exceeding the critical line but no disasters occurring, was 3%. This ratio is equivalent to ca. 2.6 times of air-shot warnings per year.

3.2.3 Regional Characteristics

Figure 5 demonstrates equal probability lines ($p = 0.005$), which are presumed to be critical lines, of each gauging station. The lines in the south western sub-area is relatively high; x-intercept ranges from 135 to 162. On the other hand, the lines in the sub-areas of north eastern (x-intercept: 114–142) and north western (x-intercept: 106–142) are relatively low. X-intercept in the southern sub-area ranges widely from 90 to 153. This result suggests that the critical lines for early warnings should be determined considering the regional characteristics.

This regional trend of critical lines seems to be the result of monsoon effects. Severe rainfall events frequently occur in the south western sub-area facing the southwest monsoon in May and cause landslides. The monsoon effects of north east monsoon are considered to be relatively weak. Therefore, the critical lines in the south western sub-area are estimated as the higher lines.

The SWI of critical line (x-intercept: 90–162) in Sri Lanka are similar value to Japanese landslide warning thresholds (73–273, average 138, as of 2020). This result suggests that SWI landslide thresholds generally range within these values even though rainfall and geological conditions are different.

4 Conclusion

Most of the past landslides and debris flows in the study area were caused by severe rainfall events in which SWI exceeded 112. It seems that SWI is a significant rainfall index to estimate landslide risks. On the other hand, slope failures, cutting failures and rock falls were caused by severe rainfall as well as minor rainfall. It is, hence, difficult to evaluate risks of small-scale slope failures, cutting failures and rock falls using rainfall indices.

It is suggested that equal probability lines ($p = 0.005$) of 30-min interval SWI and 1.5 h WR are critical lines of landslide and debris flow occurrences. The critical lines show the regional characteristics. Therefore, there is a possibility to improve the accuracy of landslide early warning by using the rainfall indices considering the regional characteristics of critical lines instead of the current uniform and constant warning thresholds in Sri Lanka. The critical value in the south-western region tends to be higher than in the northern and southern regions. It seems that the higher rainfall in the southwestern region increases the critical rainfall value of landslide occurrence.

NBRO has been trying to improve landslide warnings based on this study. It is expected to reduce miss-shot ratio by determining regional SWI critical line instead of the current constant 24-h rainfall threshold. However, available rainfall data and landslide records are limited to clarify more detail correlation between regional factors (e.g. geology, topography, hydro-meteorology) and landslide occurrence in Sri Lanka, at this moment. Therefore, it is crucial to note that further accumulation of rainfall and landslide records is necessary to continuously improve early warnings through rainfall-landslide correlation analysis in Sri Lanka.

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A Cross Case Analysis of the Upstream–Downstream Interface in the Tsunami Early Warning Systems of Indonesia, Maldives, Myanmar and Sri Lanka

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Abstract The 2004 Indian Ocean tsunami and more recent tsunami events in Indonesia have demonstrated the challenges in detecting and evaluating a tsunami threat, and the importance of communicating warning information to communities at risk. Early warning for tsunami is faced with the dilemma of time verses uncertainty due to short response times, and obvious limitations of technology and currently available scientific knowledge. Previous studies have also revealed a need for better governance, including a more strategic approach focusing on stronger integration of tsunami early warning into national and local disaster management and other public and private sectors. This chapter describes research carried out in Indonesia, the Maldives, Myanmar and Sri Lanka to better understand current tsunami early warning systems. The four countries are linked to the region wide Indian Ocean Tsunami Warning and Mitigation System. The chapter builds on the results of four national level studies to carry out a cross case analysis of the upstream–downstream interface arrangements in tsunami early warning. This is the period where the tsunami warning decision is taken at the country level, the warning information is disseminated, and an evacuation order is issued. The analysis focuses on nine critical aspects of capacity at the interface, including: decision making mechanism; clearly defined actors; centralised versus decentralised approach; standardisation of interface arrangements; technical capacity; human capacity; spatial and sociocultural aspects; vertical and horizontal coordination; and, formal and informal communication mechanisms. The results provide insights into the operationalisation of the interface arrangement in each country, as well as the technical, social, economic and political dynamics that shaped their establishment and current functioning.

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1 Introduction

The recent tsunami events in Indonesia have again demonstrated the challenges in detecting and evaluating a tsunami threat, and the importance of communicating warning information to communities at risk.

This chapter describes research carried out in Indonesia, the Maldives, Myanmar and Sri Lanka to better understand current tsunami early warning system (TEWS) arrangements and to establish priorities for capacity building in the Indian Ocean region. It builds on the results of four national level studies to carry out a cross case analysis of the upstream–downstream interface arrangements in TEWS. The results of this analysis provide important insights into the different socio-politico contexts of each country, and the similarities and differences in their approaches to tsunami early warning.

The chapter begins with an introduction to the threat posed by tsunami and some of the challenges in developing an effective early warning system that can protect communities. It goes on to introduce a conceptual framework that details the key areas of capacity that underpin effective tsunami early warning and that can be used to better understand existing tsunami early warning arrangements. The underpinning fieldwork in four countries is briefly described, followed by the methodology for a case-oriented cross case analysis. The second half of the chapter presents the results of the analysis against the key areas of capacity and discusses the implications for capacity building in the Indian Ocean region.

2 Background

Around the world, tsunami threat remains high. According to the INFORM Risk Index (2019), the disaster risk index for tsunami is the highest of all hazards in Indonesia (9.6), the Maldives (8.9) and Sri Lanka (8.2).

Some scientists have also warned that climate change will result in more tsunamis. It is widely accepted that climate change increases the frequency and magnitude of different types of disaster due to natural hazards, as well as the risk and vulnerability levels of communities. However, the subject of linkages between climate change and tsunami inundation is an emerging area of research. It is increasingly recognised that rising sea level induced by climate change could significantly increase the level of tsunami hazard to coastal land areas (Shao et al., 2019, Li et al., 2018). One of the other hypotheses is that tsunami like water waves can be caused by oceanic impacts such as seismic, landslide or volcanic geophysical events, that are potentially increased in number and size with climate change (Gusiakov et al., 2009).

Among the potential sources of tsunami, those generated by tectonic plate movements (resulting from seismic activities) have a large impact on the land areas, and hence results in large loss of lives and damage (Escaleras & Register, 2008; Lockridge, 1990). However, the nature of such tsunamis allows for systems that warn and alert exposed communities well before the tsunami impact so that people can evacuate and find shelter (Kamigaichi, 2004; Titov, 2009).

Tsunami early warning systems (TEWS) have long been identified as the single most important and effective mechanism that can be used to predict tsunamis and hence minimise the consequent damages (Basher, 2006; de León et al., 2006). The main objective of TEWS is to alert the vulnerable communities about the potential tsunami risk and provide guidance for protection, and if necessary for evacuation (Cecioni et al., 2014; IOC/UNESCO, 2015).

At the time of the IOT on 26 December 2004, the region did not have a TEWS. The tsunami resulted in the loss of over 230,000 lives and the displacement of over 1.6 million people around the Indian Ocean, with estimated economic losses of US$14 billion (UNESCO-IOC, 2019). The Intergovernmental Coordination Group for the Indian Ocean Tsunami Warning and Mitigation System (ICG/IOTWMS) was formed in response. After 8 years of international collaboration and development, facilitated and coordinated by the UNESCO Intergovernmental Oceanographic Commission, the IOTWMS became fully operational in 2013 with Tsunami Service Providers (TSPs) established by Australia, India and Indonesia.

For all the progress and improvement at the detection end of the tsunami early warning system that has been developed since the 2004 IOT, in 2014 the ICG/IOTWMS formally recognised that much remains to be done to ensure dissemination of effective warnings and improve the preparedness of communities to respond to such warnings. At the ten-year anniversary event held to commemorate the IOT (UNESCO-IOC, 2014), it was stressed that there is a need for better governance, including a more strategic approach focusing on stronger integration of tsunami early warning into national and local disaster management and other public and private sectors, and a stronger client orientation for tsunami warning services.

The complexity of the challenges for TEWS was reaffirmed by the Central Sulawesi Tsunami (September 2018) and Western Java and Southern Sumatra Tsunami (December 2018), which both caused widespread damage and loss of life in Indonesia. The summary statement from a 'Lessons Learnt' symposium after these events (UNESCO-IOC, 2020) highlighted that TEWS are faced with the dilemma of time verses uncertainty due to short response times, obvious limitations of technology and currently available scientific knowledge. It also identified a low level of public knowledge related to a near-field tsunami risk, lack of capacities of disaster management offices to deal with nearfield tsunamis, lack of proper evacuation plans and related infrastructure during tsunami emergency, poorly implemented/ineffective spatial planning, and policy related issues.

As these reviews of previous tsunami events and their responses indicate, the challenges for tsunami early warning are varied, from the need for timely and accurate monitoring, detection and evaluation of the hazard threat, to the dissemination of risk information and preparedness of communities at risk. This reflects the full spectrum of an end-to-end tsunami warning and mitigation system, as was set out in the original implementation plan for IOTWMS (UNESCO, 2011). The end-to-end system is usually defined in terms of the upstream and downstream, as documented in official technical documents and previous studies (UNESCO, 2011; de León et al., 2006). The upstream mechanism typically starts at the regional level, where an earthquake is detected, and the risk of a tsunami is forecasted. Once the warning information is received by a national authority, warning information is processed and disseminated within the country. The downstream mechanism is where the warning information and evacuation order is disseminated to the relevant authorities and general public, and if necessary, communities are relocated. Typically, the downstream mechanism continues until the risk of the tsunami is alleviated (Bernard & Titov, 2015).

Previous studies have usually focused on disparate elements of the upstream and downstream warning chain, including technical studies to develop regional and national detection and monitoring infrastructure, and local studies on evacuation infrastructure. However, this chapter will focus on more recent research into the challenges at the interface between the upstream and downstream of tsunami early warning. The interface in the context of TEWS is a relatively new concept and was not well defined in previous research. A study by Sakalasuriya et al. (2018) identified the interface as the period where the tsunami warning decision is taken at the country level, the warning information is disseminated, and an evacuation order is issued. They found this stage of early warning to be especially challenging and poorly understood. This is due to it involving a wide array of jurisdictional agencies and response partners, including regional tsunami service providers, tsunami national contact points, and a range of sub-national emergency operational centres and related actors. They also noted the socio-politico complexities in the interface arrangement, due to the wide variations across the twenty-eight countries in the IOTWMS, including their levels of tsunami threat and exposure, types of governance and institutional arrangements, levels of human and technical capacities, and social context.

The remainder of this chapter draws upon the findings of a region-wide study into the interface of TEWS. The main study was designed to understand the operationalisation of the interface arrangement in each country, and analyse the technical, social, economic and political dynamics that shaped their establishment and current functioning. These national analyses have been recorded on the interface arrangements in Indonesia (Haigh et al., 2021), the interface arrangements in Sri Lanka (Sakalasuriya, 2018, Haigh et al., 2020; Dias et al., 2020), and a comparative analysis of tsunami early warning governance arrangements at the interface in Indonesia and Sri Lanka (Sakalasuriya et al., 2020). This chapter extends these earlier analyses to present a cross case analysis of the upstream–downstream interface arrangements of the TEWS in Indonesia, Maldives, Myanmar and Sri Lanka.

3 Conceptual Framework

This chapter's analysis is built upon the conceptual framework established for the region wide study. A literature review was undertaken in order to understand the state of the art related to TEWS and establish a basis for data collection and analysis. This literature review led the authors to construct a conceptual framework that consists of nine components. This framework was used as the foundation for data collection in four countries, as well as the analysis and reporting of the results. The nine components in the framework are: decision making mechanism; clearly defined actors; centralised versus decentralised approach; standardisation of interface; technical capacity; human capacity; spatial and sociocultural aspects; vertical and horizontal coordination; and, formal and informal communication mechanisms. A more detailed description of this conceptual framework is presented in Sakalasuriya et al. (2018). Aspects related to disaster governance and politics are further elaborated in Sakalasuriya et al. (2020).

4 Methodology

After a preliminary desk study described in Sakalasuriya et al. (2018) and Sakalasuriya et al. (2020), the TEWSs of four countries were selected as case studies, namely those of Indonesia, Maldives, Myanmar and Sri Lanka. These countries are all member states of the common regional warning system, the IOTWMS. These were chosen based on the variations in criteria that affect the operationalisation of TEWS such as administrative system, extent of (de)centralisation, and proximity and exposure to tsunami threat, and recent experience. During the 2004 IOT, Indonesia and Sri Lanka were the two worst affected countries in terms of deaths, disappearances and destruction, whereas the losses of the Maldives and Myanmar were much less (NOAA, 2019a). Indonesia is the only one of these countries to have faced a significant tsunami threat since 2004 and since the establishment of IOTWMS (NOAA, 2019b). All four countries have extensive coastlines that are potentially exposed to a tsunami threat. Indonesia has approximately 6000 inhabited islands. Sri Lanka is an island nation, while the Maldives comprises 26 atolls. Myanmar has an extensive coastline but also over 4 miles of land borders. The four countries are very different in terms of geographic and demographic features, and also provide very different social and political contexts. For example, the Sri Lankan TEWS operates on a more centralised basis while the decision making in Indonesia is decentralised to local governments (Hettiarachchi & Weeresinghe, 2014; Spahn et al., 2010). There is evidence that administrative and political systems in Maldives and Myanmar also tend to be centrally operated (Faizal & Laking, 2013; Howe & Bang, 2017). These many differences provide an interesting context for comparison and wide ranging challenges for an effective early warning system.

As required by the nature of the areas being studied and based on the research questions to be addressed it was decided to use a qualitative research approach for the study. The region wide study was directed by a main academic team and supported by in-country teams in Indonesia, Maldives, Myanmar and Sri Lanka. After an initial literature review, data collection guidelines were developed by the academic teams, which were adapted into context specific tools by the country teams. Documentary analysis, semi structured interviews of key informants and focus group discussions (FGDs) were used for data collection regarding each phase of the TEWS. The data was analysed using content analysis. The findings were further validated through FGDs held in the countries with the participation of stakeholders and experts before being compiled into reports by the country teams. The final country reports were used to develop the publications and policy briefs, and to provide recommendations to national warning organisations in respective countries. The cross-case analysis presented in this paper is based on the reports and was led by the main academic team. In addition to country reports, the 2018 Status report on 'Capacity assessment of tsunami preparedness in the Indian ocean' (IOC, 2020) is used as documentary evidence for this paper. The comparative analysis is based on the conceptual framework described in Sect. 3. The case-oriented cross case analysis method was used during the data analysis, which allows researchers to explore and explain the similarities and differences between the cases (Khan & VanWynsberghe, 2008; Ragin, 2004). This method was also deemed viable given the limited time frame of the research and the nature of the data collected by different research teams in the case study countries. The data from each country were mapped into the conceptual framework, and the similarities and differences among cases were explored.

5 Results and Discussion

5.1 Decision Making Mechanism

Sri Lanka and the Maldives have a central decision-making mechanism where a significant role is played by national level institutions.

The Department of Meteorology (DoM) and the Disaster Management Centre are the key national authorities in Sri Lanka. DoM receives warnings from the TSPs and issues them to the DMC, which has the decision-making authority for issuing evacuation orders. Both DoM and DMC are under the Ministry of Disaster Management. A concern identified in the Sri Lankan tsunami decision-making mechanism is the use of personal contacts with the Ministry to agree on decisions, rather than following formal decision-making procedures and guidelines (Haigh et al., 2019).

The Maldives also has a central decision-making mechanism similar to Sri Lanka, whereby the Maldives Metrological Department (MMS) receives warnings from the TSPs and issues them to the National Disaster Management Authority of Maldives (NDMA). The NDMA, as the national decision making body, issues the orders for evacuation to relevant bodies including the island councils. A problem encountered with the Maldivian decision-making process is a confusion in identifying the difference between warning information and evacuation orders. This appears to occur due to the MMS issuing warning information directly to the general public while also issuing warning information to the NDMA for decision making. As a consequence, people often identify MMS information as evacuation orders and they start to evacuate themselves (Shadiya et al., 2019).

Indonesia and Myanmar have a similar decision-making process, which is partially decentralised. Both national and local institutions are involved in the decision-making process.

In Indonesia, the Indonesian Agency for Meteorology, Climatology and Geophysics (BMKG), Indonesian National Board for Disaster Management (BNPB), Local Disaster Management Organisation (BPBD), and the local mayor's office are involved in the tsunami early warning process. There is a clear hierarchy from BMKG as an information provider and decision-maker to provide warning information to the relevant authorities. The actual evacuation order is taken at the local level by the Mayor and with the support of the local disaster management organisation. This reflects a wider decentralisation of government across all government sectors of Indoensia. Although this can be seen to empower local level decision making, it has also resulted in some different practices at the local level. There are concerns that local level actors may not have the capacity and experience to make such critical decisions. There is now recognition that there is a need to strengthen guidelines for local political actors (Rahayu et al., 2019).

In Myanmar, the Department of Meteorology and Hydrology receives information from TSPs and issues them to the Department of Disaster Management (DDM). But, the responsibility of the DDM is only to convey the message to regional, district, town and village level government administrative department/disaster management bodies. The decision to issue the order for evacuation is taken by these administrative department/disaster management bodies at different levels, depending upon predefined emergency status levels and associated criteria. A concern with this approach is the time taken for decision making. Different levels of general administration department (GAD) need to be consulted. If one level is unable to handle the situation, it is passed on to a higher level and these practices consume a considerable amount of time (Aung et al., 2019). Tsunami threats are sudden onset events, which typically afford anything from a few minutes to a few hours to issue warning information to communities at risk. This is very different from, for example, a typical cyclone, which is usually forecast several days before the event. It illustrates the need to tailor decision making processes to reflect the amount of time available from a hazard being detected, to when it directly impacts communities at risk.

5.2 *Clearly Defined Actors*

All four countries have clearly defined National Tsunami Warning Centres (NTWCs) and National Disaster Management Organisations (NDMOs) in their TEWS. This reflects standard roles as defined by regional guidelines provided by the IOTWMS.

They also have defined actors for downstream operations as well. For example, Sri Lanka has identified roles for the Department of Fisheries, Ministry of Health, The Tri-forces (Army, Navy and Air Force), Police, the Transport Board, District Disaster Management Offices and Grama Niladaris (the lowest administration level of Sri Lanka).

Although these actors are identified, a key issue identified in all four countries is fragmented coordination among them (Aung et al., 2019; Haigh et al., 2019; Rahayu et al., 2019; Shadiya et al., 2019).

This is especially challenging in the Maldives, where there is a need to coordinate operations at an island level. The Maldives has a population of approximately 530,000 people spread across 200 inhabited islands, grouped in clusters, or atolls. They also have very little experience of tsunami events. The island level authorities do not have adequate knowledge of their roles and responsibilities in the early warning mechanism (Shadiya et al., 2019).

Similar to Sri Lanka and the Maldives, Indonesia has designated interface institutions but, there are issues in the coordination mechanism. The Service Guidebook for Ina-TEWS is the principal document prepared to guide all the stakeholders with-in the Ina-TEWS. There are gaps in the clarity of the guidelines given in the service guide book. For example some roles that are evident in practice, do not appear in the guidance (Rahayu et al., 2019).

The situation in Myanmar is even more complex. As detailed in Sect. 5.2, the evacuation decisions are taken by GADs at National, Regional, District, Town and Village Committees depending on the emergency level There are twelve working committees under each level and the coordination mechanism among these levels is not documented or demonstrated in Myanmar's TEWS (Aung et al., 2019).

5.3 *Standardisation*

In Sri Lanka, standard operating procedures (SOPs) are prepared by institutions such as MDM, DMC and DoM for their in-house use. A National Emergency Operation Plan (NEOP), which was developed by the DMC in 2015, provides some general guidelines on early warning and emergency response situations. However, these SOPs of different institutions are not formally integrated. The absence of a common guideline that can be followed by all stakeholders has created a lack of understanding among the individuals within the institutions. For example, there are disputes between DoM officers and DMC officers in understanding their roles, such as 'who contacts the regional TSP and the Ministry?' and 'who takes the final warning decision?'.

Since this was revealed during this research study, an integrated SOP was developed by the key stakeholders. This integrated SOP was tested during the 2018 Indian ocean-wide tsunami (IOWave) exercise, further improved and later adopted (Amaratunga et al., 2019; Haigh & Amaratunga, 2018).

Indonesia holds the Service Guidebook for its TEWS as the principal document prepared to guide all the stakeholders. Further, there are guidelines available within the individual institutions, both at national and local levels. As stated in Sect. 5.2, there are some gaps in the clarity of the guidelines given in the service guide book as some of the roles and responsibilities of key institutions are not clear (Rahayu et al., 2019).

Like in Sri Lanka, Maldives has developed a NEOP which provides certain general guidelines on early warning and emergency response situations. Besides this, SOPs are developed for the national level institutions, but these do not cover island councils who conduct the evacuation process (Shadiya et al., 2019).

The Department of Meteorology and Hydrology of Myanmar has a SOP for issuing a tsunami warning. As per the National Disaster Management Law 2013, all institutions related to disaster management should have their own SOPs and need to update them every 4–5 years (Aung et al., 2019, UNESCO/IOC, 2018). Although there are several guidelines and SOPs at the national and department level, they are not integrated into a single work plan for the operation. At the same time, the SOPs for local governments are not clearly defined in Myanmar (Aung et al., 2019).

5.4 Technical Capacity

The findings of this study found that national level technical capacities of all four countries are at a broadly acceptable level, but that each has specific challenges, primarily at the local level.

Sri Lanka does not have adequate technical capacities at the district and local level to deal with emergencies. Also, this study identified a need to reconvene a national technical advisory committee for tsunami in Sri Lanka, which could provide ongoing advice and guidance to relevant agencies and that can identify and address relevant research and technical gaps, and guide plans for capacity building (Haigh et al., 2019). This committee was originally established after the 2004 tsunami event, but over time had become dormant.

In Indonesia, the national level technical capacity is extremely high as the country is one of three regional TSPs that provide information for the whole IOTWMS. Downstream, the technical capacities are far less and it was found that tsunami warning dissemination was sometime disrupted due to the impact of an earthquake or a power outage (Rahayu et al., 2019).

The technical capacities of island councils in the Maldives also require improvement. For example, there is a need to provide satellite phones to all island councils. Currently, standard phones and social media groups such as 'VIBER' are in use to disseminate warnings to island councils which are easily overwhelmed in emergencies (Shadiya et al., 2019).

In Myanmar, the downstream warning dissemination modes are not clear. For example, it is not clear how the early warning information is communicated to the village level committees who decide to evacuate people. The lack of electricity in most of the villages is also a critical technical issue and can prevent the dissemination of warning information to the village level (Aung et al., 2019).

5.5 Human Capacities

Similar to technical capacities, human capacities were also found to be generally acceptable at the national level, but more problematic at a sub-national level.

The key institutions of Sri Lanka and Indonesia are very well connected with relevant political bodies. In Sri Lanka, in case of an emergency and warning issuance, both the DMC and DoM inform the secretary of the ministry about the changing developments and the Secretary updates the Minister who informs the President. As the national disaster management institution, the individuals in DMC are under direct scrutiny and well-connected to political actors (Haigh et al., 2019).

In Indonesia, the Director-General of BMKG, Indonesia, is the head. An inspector and a main secretary are the two main leads under the Director-General, and the rest of the staff function under their guidance (Rahayu et al., 2019). Like DMC in Sri Lanka, BNPB is under the direct supervision of the President of the Republic of Indonesia.

However, several stakeholders in the Sri Lanka TEWS, such as NARA (who is providing sea-level data), do not operate 24/7 as they do not have adequate staff. Also, DoM, as the NTWC of Sri Lanka often faces issues with its human resources due to the heavy workload and staff being stretched into several responsibilities. Also, some DMC staff carry a passiveness towards a potential tsunami as they lack up to date knowledge and awareness about the level of tsunami threat to Sri Lanka (Haigh et al., 2019). It was found that some staff had become complacent, most likely due to the country not experiencing a tsunami since 2004.

In Indonesia, there is a need to ensure provision of adequate training to the local Mayors, as they take the evacuation decision at local levels. Since the Mayor is a political actor, EOC specialists need to support and provide essential training to the mayors. The personnel at EOCs also need effective leadership skills to determine an evacuation order in the absence of the Mayor (Rahayu et al., 2019).

MMS as the NTWC of Maldives has a good human resource capacity. However, the NDMA needs for human resources for shift work as they sometimes limit their working hours due to non-availability of shift staff. Currently, when there is a yellow or a red alert, all the staff at NDMA are required to report for work, but, this can pose an extreme threat and a delay in decision making in case of an emergency. Further, it is was also evident that trained staff after 2004 Tsunami have now left their positions and the new staff have not received training on TEWS. The study did not reveal the human capacities within the island councils, which need further investigating (Shadiya et al., 2019).

The DMH of Myanmar, as the NTWC, holds an adequate human capacity, but, there is a lack of human capacity at the village level. As per Myanmar's TEWS when the alert level is number 5, the village level committees are responsible to take the evacuation orders and to pass it to the next level (town level) if they cannot handle the situation. In order to take such a decision, as well as to decide the emergency level, they would require adequate training and knowledge on the early warning mechanism. In reality there is very little training or support at the local level (Aung et al., 2019).

5.6 Spatial and Socio-Cultural Aspects

Hazard mapping is a key spatial aspect in improving the early warning mechanism. Indonesia and Sri Lanka have hazard mapped whole coastal regions, which is a major improvement in strengthening the TEWS of respective countries. However, it is noted that Myanmar needs to improve their hazard mapping as they have currently mapped only one village which is Aung Hlaing Village, Labutta Township, Ayeyarwady Region (UNESCO/IOC, 2018, Aung et al., 2019).

However, even when maps are available, they may not be fit for purpose. For example, in Indonesia the maps are available only at a macro scale, and as a result, they cannot be used for planning an evacuation at the local level.

Countries also have specific cultural challenges to overcome. In Sri Lanka, people in certain areas tend to believe and follow predictions from astrologers rather than follow scientific information from early warning authorities (Haigh et al., 2019). In the Maldives, some people in islands believe that a tsunami is a punishment from God and therefore there is no way to escape it. Accordingly, they do not follow the early warning information and orders (Shadiya et al., 2019). The Maldives also has a very high number of tourists per capita, many of whom would be unfamiliar with a tsunami threat and would be unlikely to have participated in any local level training or awareness raising. In Myanmar, many people are facing poverty and hunger, and these tend to take precedent over, for example, efforts to understand the early warning mechanism (Aung et al., 2019).

5.7 Ongoing Evaluation

The IOTWMS organises region wide 'IOWAVE' exercises every other year to simulate tsunami warning processes. Most of the twenty eight countries in IOTWMS participate but it is not compulsory. They also tend to focus on national level processes, while participation downstream is minimal in most countries (Haigh et al., 2019; Rahayu et al., 2019; Shadiya et al., 2019). Twenty one countries also participated in a 2018 survey to assess tsunami preparedness, which has informed capacity building in the region (UNESCO/IOC, 2018). Countries are also encouraged to carry out national and local level simulation exercises, but these appear to be very ad-hoc and approaches differ greatly across countries. Indonesia for example, has conducted local level exercises in high risk areas since the 2004 event. At the time of the study, the DMH of Myanmar was also organising training courses for public awareness and knowledge sharing on disaster risk reduction to ensure the warnings reach the public (Aung et al., 2019).

6 Conclusion

Table 1 provides a summary of the findings to emerge from the study across the four countries. It also sets out some recommendations for capacity building that have emerged through the research.

The IOTWMS is a region wide system for TEWS and covers twenty eight countries. The guidance issued at the regional level has led to some commonalities across countries, such as the key roles of institutions and aspects of the SOP, especially the protocols between regional TSPs and national levels actors. However, this study has revealed important variations in how the system operates at the national and sub-national levels. These differences are not suprising as the contexts within which the TEWS operate are also very different.

The highly dispersed, island populations of Indonesia and the Maldives pose a very different challenge to that of Sri Lanka or Myanmar. Also, while all countries were hit by the 2004 IOT, Indonesia has experienced multiple devastating tsunami since then and is more highly exposed to future events. It has invested heavily in early warning as a result and it appears to be a national priority. Due to the devastation experienced in 2004, Sri Lanka also made considerable effort to develop its TEW capability, but over time and as memories of the event recede, it is also clear that some of these capacities have faded. In contrast, the Maldives and Myanmar were not as badly impacted by the 2004 event. Other threats, such as climate change in the Maldives, or cyclones in Myanmar (especially after Cyclone Nargis in 2008) appear to have taken precendence. In the case of Myanmar, it appears that their very decentalised decision making structures have not been adapted to fit the specific challenges of a tsunami, which may need a decision to be taken in very limited time and with limited information.

Despite the many differences, a common challenge encountered across countries is the need to develop adequate capacities at the sub-national levels. The regional system focuses warning information on a central contact point at the national level. In all countries, most of the expertise and capacities is also focused on these national actors, especially the NTWC and NDMO. However, in all countries, a range of subnational actors are also involved in conveying warning information to communities at risk. It is therefore vital that these sub-national actors are provided with adequate capacities

Table 1 Comparison of countries against critical areas of capacity in the interface arrangements for tsunami early warning

Areas of capacity	Sri Lanka	Indonesia	Maldives	Myanmar	Similarities/differences	Gaps/issues	Recommendations
Decision-making mechanism	• Central • Significant institutions operate at the National level • Institutions are under the ministry	• Partially decentralised • Both national and local stakeholder institutions are involved • Clear hierarchy at national and local levels • Local mayor issuing the evacuation order	• Central • Significant institutions operate at the National level	• Mixed decision-making mechanism • Both national and local stakeholder institutions are involved • The decision to issue the order for evacuation is taken by administrative department/disaster management bodies in different administrative levels depending on the emergency status level	• **Sri Lanka and Maldives**—centralized national level mechanisms from warning detection, decision making to dissemination • **Indonesia**—national mechanism for warning detection and to decide to warn the authorities (dissemination), but evacuation orders are taken at the local level • **Myanmar**—similar to Indonesia, detection and the decision to disseminate warnings taken at the Nation level, but, evacuation orders are taken by different administrative bodies (can be national or local depending on the emergency status level)	• **Sri Lanka**—personal contact with ministry to agree on decision • **Indonesia**—different practices at the local level in decision making • **Maldives**—warning dissemination to the public by both MMS and NDMA, people are often confused in identifying the correct evacuation order • **Myanmar**—time management for decision making as the process is so long	• **Sri Lanka**—needs to follow formal mechanism in decision making • **Indonesia**—clear guidelines to political actors on decision making at the local level is needed • **Maldives**—provide awareness to people in differentiating dissemination information and evacuation orders • **Myanmar**—clear policy guidance for decision making
Clearly defined actors	• Regulator- MDM • NTWC/TWFP-DoM • NDMO-DMC	• Regulator- BMKG • NTWC/TWFP-BMKG • NDMO-BNPB	• Regulator and NDMO-NDMA Maldives • NTWC-MMS	• NTWC- DMH • NDMO-DDM	• Defined actors in all four countries	• Unclear roles and responsibilities • Discrepancies of actions	• Need to clearly refine roles of each actor

(continued)

Table 1 (continued)

Areas of capacity	Sri Lanka	Indonesia	Maldives	Myanmar	Similarities/differences	Gaps/issues	Recommendations
Standardisation	• SOPs prepared by MDM, DMC, and DoM for their internal use • Availability of NEOP	• Service guidebook-principal document prepared to guide all the stakeholders with-in the Ina-TEWS • Guidelines available within the individual institutions, both at national and local levels	• NTWC and NDMO-SOP available • No SOPs for island councils	• NTWC-SOP available • All institutions related to disaster management should have their own SOPs and need to update them every 4–5 years	• SOPs for national institutions in all four countries • NEOP plans are developed in Sri Lanka and Maldives • Service guidebook-principal document prepared to guide all the stakeholders with-in the Indonesian-TEWS	• **Sri Lanka**—some discrepancies in SOPs, SOPs of different institutions not formally integrated, absence of a common guideline • **Indonesia**—the roles of BNBP, EOC, and BPBD were not specified as key warning conveyors and decision-makers in the regulations • **Maldives**—island councils do not have SOPs to conduct evacuation • **Myanmar**—several guidelines and SOPs at the national and department level, they are not clearly integrated into a single work plan for operation, SOPs of GADs not defined at each GAD level, severe delays in the decision-making process	• **Sri Lanka**—need to use the DMC formally adopted synergised SOP to bring the coordination • **Indonesia**—clarity of the guidelines should be improved • **Maldives**—needs to standardise evacuation procedure at island councils • **Myanmar**—needs to standardise the decision-making process at the GADs, integrate all SOPs into a single work plan

(continued)

Table 1 (continued)

Areas of capacity	Sri Lanka	Indonesia	Maldives	Myanmar	Similarities/differences	Gaps/issues	Recommendations
Technical Capacity	• Better technical capacity at the National level • Inadequate technical capacities at the district and local level to deal with emergencies	• Better technical capacity at the National level • Equipment for tsunami warning dissemination often dysfunctions, due to the impact of earthquake or power outage	• Better technical capacity at the National level • Technical capacities of Island Councils should be improved	• Better technical capacity at the National level • *Technical capacities of different levels of GADs are not revealed in this study*	• Better technical capacity at the National level in all four countries is a common feature	• Inadequate technical capacity at local levels is a common problem in all four countries • **Maldives** standard phones and social media groups such as 'Viber' in use to disseminate warnings to island councils, often jammed in emergencies • **Myanmar** Lack of electricity in most of the villages hinders downstream communication in emergencies	• **Sri Lanka** needs a national technological advisory committee to revisit the capacity needs • **Maldives** required to provide satellite phones to all island councils

(continued)

Table 1 (continued)

Areas of capacity	Sri Lanka	Indonesia	Maldives	Myanmar	Similarities/differences	Gaps/issues	Recommendations
Human capacity	• Politically well-connected with the key institutions • Better human capacity at National level institutions • Regional and local level institutions do not operate 24/7 due to a lack of human capacity	• Politically well-connected with the key institutions • Local-level human capacity needs increasing • Mayor at local level take decisions on evacuation orders	• **MMS has the adequate human capacity** • NDMA more human capacity for shit work *Information on human capacity at Island staff were not clearly revealed from this study*	• DMH-well established human capacity • Local/village level decision makings capacity is not adequate	• Generally, in all four countries good human capacity at national level, local level human capacity needs improving	• **Sri Lanka**—DoM heavy workload for staff, DMC staff passiveness towards potential Tsunami • **Indonesia**—wrong interpretation of warning due to lack of understanding in local level, Mayor's need proper training on early warning process, EOC personnel needs training on effective leadership skills to determine an evacuation order in the absence of the mayor • **Maldives**—trained staff have left from relevant positions, NDMA needs more staff for shift work • **Myanmar**—lack of decision-making knowledge for local communities	• **Sri Lanka**—staff training on potential Tsunami threat • **Indonesia-** Mayors require training and effective leadership skills • **Maldives**—continuous training, to improve their knowledge on updated bulletin's new regional developments • **Myanmar**—village level people's decision-making skills need to be improved as they take are supposed to local evacuation decision

(continued)

Table 1 (continued)

Areas of capacity	Sri Lanka	Indonesia	Maldives	Myanmar	Similarities/differences	Gaps/issues	Recommendations
Spatial and socio-cultural aspects	• **Hazard maps** • All of the coast around Sri Lanka has been hazard mapped at the scale of 1: 50,000 by DMC	• **Hazard maps—done** major improvement	• **Hazard maps**—not clearly revealed from the study	• **Hazard mapping**—need to improve hazard mapping in Myanmar	• Hazard maps are done in Sri Lanka and Indonesia. Myanmar need to improve them	• **Sri Lanka**—predictions given by astrologers/people tend to believe these • **Indonesia**—hazard maps are available only on a macro scale, and as a result, they cannot be used for planning for evacuation at the local level • **Maldives**—belief as God's punishment • **Myanmar**—villagers struggle for their daily life and food, no intention to prepare for a potential hazard	• **Indonesia**—further decentralisation and empowerment of local communities in terms of hazard mapping is required
Ongoing evaluation	• Participated IOWAVE 2018	• Participated IOWAVE since 2008	• Participated IOWAVE 2018	• *Information on this was not clearly revealed from this study*			

Table 01 Summary of the cross case analysis

to fulfil their responsibilities. This is especially critical in countries like Indonesia and Myanmar, where decision making has been partially delegated to sub-national levels.

Looking forward, it is also evident that there is the potential for experiences to be shared across countries. The IOTWMS is using the input from this research and a 2018 capacity assessment of tsunami preparedness to inform capacity building and training efforts across the Indian Ocean region. As part of this, there will be opportunities for countries to share details of their approaches and learn from different contexts.

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Integrating Health into Disaster Risk Reduction

Management of the Dead in Disasters: Knowledge, Attitudes and Self-Reported Practices Among a Group of Army Soldiers in Galle District, Sri Lanka

Udalamaththa Gamage Gihan Chaminda and Janaki Warushahennadi

Abstract

Introduction
Improper "management of the dead (MoD)" in disasters can hinder the identification, leads to loss of important forensic evidence and affects the dignity of the dead. Army soldiers play a vital role in dead body management in disasters.

Objective
To describe the knowledge, attitudes and self-reported practices on MoD in disasters among a group of army soldiers in Galle district, Sri Lanka.

Methods
This descriptive cross sectional study was conducted using a self-administered questionnaire. Based on the percentage of correct responses, participants were classified into three groups denoting their overall knowledge using pre-determined cut-off values (>70%—"good", <50%—"poor", 50–70%—"moderate" level of knowledge).

Results
A study population of 188 army soldiers was included in the study. A majority (61.2%) had a moderate level and 32.4% had a good level of overall knowledge. The knowledge on wearing face masks by dead body recovery teams (8%) and spraying disinfectants to dead bodies (30.9%) was poor. Respectively 21.8% and 52.1% believed that funeral rites are not important and dead bodies of foreign nationals should be treated better than locals. During the dead body recovery process 59% had used gloves and boots.

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Conclusions
Even though a majority had either moderate or good level of overall knowledge, deficiencies of knowledge in certain aspects were evident.

Keywords Management of dead · Disasters · Army soldiers · Sri Lanka

1 Introduction

Improper "management of dead (MoD)" in disasters can lead to loss of valuable forensic evidence, delay in identification of the deceased, and prelude dignified burial (Weeratna et al., 2016) and may have a significant impact on the wellbeing of survivors. Thus, inappropriate MoD has social, psychological, economical and legal consequences on the survivors (Weeratna et al., 2016).

Experience from the natural disasters such as the "2004 Indian Ocean Tsunami" has shown that the 'first responders' play an important role in MoD in disasters (Cordner et al., 2016). These first responders can do a lot to give the best possible opportunity to investigators to identify the deceased and clarify the fate of the missing people (World Health Organization, no date). In other words, the early work of first responders determines the success of much of the work done by medico-legal experts later.

Among the stakeholders involved in disaster response, Army plays a key role and their role has increased in the recent past due to various reasons such as increased incidence and magnitude of natural disasters and increased interest of military institutions in disaster response (Thapa, 2016).

In Sri Lanka army soldiers play a vital role in the process of MoD in disasters. They act as either responsible or supporting persons in almost all activities in MoD in disasters (Weeratna et al., 2016). The importance of their role was clearly evident during missions of recovery of human remains in recent disaster situations in Sri Lanka such as the collapse of garbage dump at Meethotamulla and landslides at Meeriyabedda and Aranayaka.

The objective of this study was to describe the knowledge, attitudes and self-reported practices on MoD in disasters among army soldiers in army camps in Galle District, Sri Lanka.

2 Materials and Methods

This descriptive cross-sectional study was carried out in two selected army camps in the Galle district, Sri Lanka in 2017. The study population included all army soldiers working in two army camps during the days of data collection. Since data was collected from the entire population, sample size calculation and sampling technique were not applicable. The ethical approval was granted by the Ethics Review Committee of the National Hospital of Sri Lanka.

The data collection instrument was a pre-tested self-administered questionnaire in Sinhala and Tamil languages which are the two native languages in Sri Lanka. The contents of the questionnaire were in accordance with the objectives of the study and consisted of close ended type questions in four sections. The first section consisted of basic socio-demographic data of the participants. Thirty three true/false type questions regarding the knowledge on MoD and attitudes on MoD in disasters were in the second and third sections consecutively. Fourth section consisted of questions on self-reported practices in MoD in disasters. All the soldiers who were physically present at the army camps on the days of data collection were invited to participate in the research and voluntary verbal consent was obtained by the principal investigator.

Statistical analysis of data was performed using the statistical package for social science (SPSS, version 21). Each correct response in the second section was awarded one mark. A total score for overall knowledge was obtained by summing the marks given for each correct response. The sum of correct responses was converted into percentages, with 100% denoting the correct responses to all the items.

Based on the proportion of correct responses, army soldiers were classified into three groups denoting their different levels of overall knowledge using predetermined cut-off values. Those who scored >70% were categorized as having a "good" level of overall knowledge on MoD in disasters, <50% were categorized as having a "poor" level of overall knowledge while those with a score of 50–70% were considered as having a "moderate" level of knowledge. Socio demographic characteristics, individual items assessing the knowledge, attitudes and practices on MoD in disasters were described using frequency distributions. Overall level of knowledge was cross analyzed with service duration and highest educational level to identify possible associations using chi square test of independence. A probability value of less than 0.05 was considered as significant.

3 Results

The study included 188 male army soldiers with a response rate of 94.5%. While 51.6% (n = 97) were in 31–40 years of age group, 31.4% (n = 59) were 30 years old or below. Only 43.6% (n = 82) had passed General Certificate of Education (Ordinary Level) examination while the rest had the highest educational level below the General Certificate of Education (Ordinary Level) examination. Majority (64.9%, n = 122) had a service of 10 years or more in the Army.

The participants were asked different aspects of the MoD in disasters. Out of the total, 67.6% have answered correctly to the false statement "Dead body recovery is the most urgent task in a disaster" while 81.9% knew that establishment of a scene management team is necessary. Respectively 87.2% and 92% were aware that body receiving point has to be determined and a Body Recovery Register should be maintained before dispatching the bodies from the scene. When it comes to the numbering of dead bodies, 93.6% knew that a unique reference number should be given to each body and 87.2% were aware that the number tags should be attached to the wrist or ankle of a complete body.

Majority (92%) agreed that the bodies should be released after confirming the identification and 36.2% has responded correctly to the false statement of obtaining a single photograph of a body is adequate. 51.6% and 54.8% respectively responded correctly to the false statements of every attempt should be made to identify the bodies and all attached personal belongings should be removed at the scene itself.

When it comes to the fragmented bodies 45.7% stated that every body part should be considered as a separate individual and 52.7% thought that all fragmented pieces of a particular area could be collected into a one container. While 66.5% have responded correctly as false to the statement of recovery team should attempt to match body parts at the scene, 52.1% have responded correctly to the false statement of the personal belongings separated from the body belongs to the closest body.

Majority (77.1%) stated correctly that the bodies should be placed in separate body bags with personal belongings (74.5%) sealed and plastic sheets, bed sheets or other available material is an alternative if body bags are unavailable (86%). But only few (34%) knew that the ambulances should not be used to transport the bodies.

When the bodies are transported to the mortuary the storage of dead bodies is essential until the medico-legal investigations are completed. Out of the total, 76.6% were aware that the refrigeration of dead bodies between 2 and 4 °C is the best option for storage of bodies but few (47.3%) were aware that the temporary burial is also a good option. Though 71.8% knew that laying bodies on top of each other with an intervening layer of soil in temporal burial sites is wrong, only 37.2% knew that using the ice (frozen water) for storage of bodies is not useful.

Most of the participants (92%) knew correctly that handling dead bodies carries a small risk of infection through contact, but only few (8%) knew that wearing a face mask and spraying disinfectants (30.9%) to dead bodies is not essential.

Several administrative issues which are commonly faced by the first responders at the scene of mass disasters were included into the questionnaire. 91% of the participants were aware that legal problems could arise for relatives as a consequence of mismanagement of dead. But only 52.1% and 44.7% have given a correct response to the false statements 'politicians can participate' and 'direct communication with outsiders/media should be done' respectively. Only 51.1% knew that the journalists should not be allowed to the scene immediately after the disaster.

The majority (61.2%, $n = 115$) were found to have a "moderate" level of overall knowledge on management of the dead in disasters whereas 32.4% ($n = 61$) were found to have a "good" level of overall knowledge. Items of the questionnaire for which the participants′ knowledge was poor are shown in Table 1. Level of education was significantly associated with the overall knowledge on MoD in disasters (Chi-square 6.023, $df = 2$, $p < 0.05$). There was not enough evidence to suggest a significant association between the service duration of soldiers in army with the overall knowledge (Chi-square 1.142, $df = 2$, $p = 0.565$).

Table 1 Items in the questionnaire for which the participants' knowledge was poor (n = 188)

Item	Percentage of participants who responded correctly
Wearing face masks is essential for teams involved in dead body recovery **(False)**	08.0
Spraying disinfectants to dead bodies is essential **(False)**	30.9
Ambulances should not be used to transport the dead bodies **(True)**	34.0
Obtaining a single photograph in relation to an individual body is adequate **(False)**	36.2
Ice (frozen water) should be used for storage of dead bodies **(False)**	37.2
Direct communication with outsiders/media and revealing information should be done by all the team members **(False)**	44.7
Every body part that is completely separated should be treated as a separate individual **(True)**	45.7
Temporary burial is a good option for immediate storage where no other method is available **(True)**	47.3

Attitudes of the study population were assessed using ten attitudinal statements (Table 2).

Out of the total 130 (69.1%) had experience in MoD as army soldiers. They were asked about several practices which need to be adapted in MoD in disasters and the practices they reported to have followed are illustrated in the Table 3.

4 Discussion

The level of overall knowledge of the study population is satisfactory with the majority (93.6%) having either moderate or good level of overall knowledge on MoD in disasters. Yet considerable gaps in certain important aspects of MoD were evident. In particular, knowledge on wearing face masks, taking photographs, spraying disinfectants to dead bodies and use of ambulances to transport the dead was poor.

Though 92% knew that individuals handling dead bodies have a small risk of infections via contact with blood and faeces, only 8% knew that wearing face masks is not essential for dead body recovery teams. The facemasks do not filter or provide protection for a considerable period of time and they can slow down some tasks of the users such as moving, storing, and preparing corpses. Moreover, the danger of

Table 2 Percentage of attitudes of army soldiers on MoD in disasters (n = 188)

Statement	Agree	Disagree	Not answered
Pre planning for disasters is a waste of money and time as disasters are unpredictable	25.5	72.3	2.1
Following guidelines is impractical in real disaster situations	33.0	65.4	1.6
Funeral rites are not important in MoD in disasters	21.8	76.1	1.1
Mistaken identity is not a big issue to be worried	23.4	75.0	1.6
Management of bodies of foreign nationals should be treated better than the locals	52.1	47.3	0.5
Dead bodies of children should not be given the priority	10.1	89.4	0.5
Unidentified bodies should be buried in common graves to save time and money	48.9	50.0	1.1
Necessity of members of the affected families to know the fate of their loved ones should not be a priority	27.7	71.3	1.1
There's no need to respect dead bodies	12.8	86.7	0.5
Identification of dead is not important in disasters as there are large numbers of casualties	19.7	79.3	1.1

Table 3 Practices in MoD in disasters (n = 130)

Practice		Percentage
Use of gloves and boots in dead body recovery process **(Yes)**		59.0
Use of ambulances to transport dead bodies **(No)**		58.0
Placing of each dead body in a separate body bag **(Yes)**		54.8
Obtaining photographs of the disaster scene and dead bodies **(Yes)**		53.7
Sealing of body bags after placing bodies **(Yes)**		53.2
Assigning a Unique Reference Number to each body **(Yes)**		51.6
Tagging of each body with a Unique Reference Number **(Yes)**		51.6
Establishment of a scene management team immediately after a disaster **(Yes)**		44.7
Matching of body parts with incomplete bodies at the scene **(No)**		41.5
Burial of a large number of dead bodies in a common grave **(No)**		35.6

contamination via respiratory tract is minimal since there is no respiratory function in dead bodies (Management of dead bodies in disaster situations, 2004).

According to the available guidelines, dead bodies should not be transported in ambulances and vehicles used for transportation of consumable items (Management of dead bodies in disaster situations, 2004) and only 34% were aware of it. Assigning a unique reference number to each body or body part is a must (Weeratna et al., 2016) to avoid loss of bodies, to ensure traceability and correct documentation, and to enhance identification of the deceased (Cordner et al., 2016) and majority (93.6%) in the study were aware of it.

Usually the bereaved want to see the corpse to say "goodbye" and to conduct ceremonious funerals (Sumathipala et al., 2006). In a study done in Indonesia on individuals involved in responding to humanitarian needs immediately after the disasters, participants have identified "the right to mourn and the right to be treated according to one's religion even after death" (Bagherzadeh, 2014). Our study also showed similar findings and only 21.8% believed that funeral rites are not important.

A noteworthy finding of this study is the attitude of more than half (52.1%) of the study subjects that management of bodies of foreign nationals should be treated better than the locals. The Guidelines laid by College of Forensic Pathologists of Sri Lanka clearly state that, "Every victim, foreign or Sri Lankan, would be treated equally" (Weeratna et al., 2016). It is even well documented in the Field Manual for First Responders that; "Pressure to prioritize the finding of foreign nationals must not be allowed to distort the priorities of a systematic local approach to identifying all the dead" (Cordner et al., 2016).

This study showed that a majority of participants had favourable attitudes in many aspects of the MoD in disasters although there were some negative attitudes to a certain extent. In a study conducted among health care workers, attitudes of all respondents towards MoD following disasters were favourable and most of the participants had highly positive attitudes towards mass fatality management (Rajapaksha et al., 2015) which may be due the knowledge from the medical education, training etc.

Regarding self-reported practices pertaining to MoD in disasters, more than half (54.8%, n = 103) reported that they have placed each dead body in a separate body bag whereas (51.6%, n = 97) have stated that they have assigned and tagged a Unique Reference Number to each dead body. But according to Perera and Briggs (2007), following the Indian Ocean Tsunami in 2004, tagging of dead bodies with 'permanent identification codes' was not done before disposing them.

To our knowledge, this is the first study conducted in Sri Lanka to describe the knowledge, attitudes and practices on MoD in disasters among first responders. It could be considered as a major strength of this study and the findings will aid to bridge the gaps in the subject. One limitation of this study is that it was confined to male soldiers. Secondly, as data was collected using a self-administered questionnaire, there's a possibility that participants may have provided socially desirable responses, especially with regard to practices rather than the actual practices that they had engaged. There could be an element of recall bias with regard to practices since the data asked about practices were not confined to the recent past.

Even though a majority of army soldiers had either "moderate" or "good" level of overall knowledge on MoD in disasters, deficiencies of knowledge in certain aspects were evident. A majority of participants had more favourable attitudes in many aspects of MoD in disasters although there were some negative attitudes to a certain extent. There is a space for improvement in certain practices of MoD in disasters.

This study recommends improving the training opportunities for army soldiers to enhance their knowledge and experience on MoD in disasters. More consideration should be given to offer specific instructions on different aspects of dead body management during training programmes.

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Stakeholder Engagement in Dengue Control; One Year After the Major Dengue Outbreak in Sri Lanka—Lessons for Future Mosquito-Borne Infection Prevention and Control

D. S. A. F. Dheerasinghe and M. Cader

Abstract Dengue is the fastest spreading mosquito-borne viral disease in the world spreading from tropical regions to most subtropical regions, causing human suffering and considerable socioeconomic losses and hence considered as a global public health challenge. The frequent emergence of epidemics with more severe forms of the disease has now led Sri Lanka to be categorized as a hyper-endemic country, producing the largest outbreak in 2017 with an incidence of 833.9 per 100,000 population and with 0.24% case fatality rate. As a resultant, proactive strategies were identified for its prevention and control. Accordingly, stakeholder groups were identified on evidence generated by the various Dengue surveillance mechanisms and the Presidential task force was reconvened in 2017 to interlink the health sector with stakeholder ministries. This analysis aims to evaluate the outcomes of stakeholder engagement in Dengue control after implementation of intensified interventions during 2017 major Dengue outbreak by comparing relevant premise inspection and vector surveillance data for the year 2017 and 2018. A desk-based review was conducted to describe the premise inspection surveys and entomological surveillance data in order to explore the sustainable engagement of key stakeholders in dengue control in Sri Lanka. During the 2017 outbreak of dengue the following key interventions were adopted namely; the reformation of the multi-stakeholder accountability framework, implementation of integrated actions via multi-stakeholder engagement, and launching of widespread communication campaigns to empower stakeholders. The Impact of stakeholder engagement was measured by using premise inspection data gathered via door to door Special Mosquito Control Campaigns (SMCCs) in 2017 and 2018. Accordingly, nineteen (19) SMCC's covering 2.7 million premises and Thirteen (13) SMCC's covering 1.4 million premises were carried out in 2017 and 2018 respectively. Of them, 20 and 21% of premises reported having potential breeding places and 1.98 and 2.29% of premises were reported to have larvae positive in the respective years. Thus, the data revelation pointed towards an overall increase in potential

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and positive breeding places in 2018 compared to 2017. The entomological survey results for the years 2017 and 2018, when compared, also reflected an increase in premise index (PI) in 13 out of 26 districts, ranging from 1.9 to 109%.

Keywords Dengue · Stakeholder engagement · Desk-based review

1 Background

Dengue is the fastest spreading mosquito-borne viral disease which shows a 30-fold increase over the past 50 years (Bhatt et al., 2013; Roth et al., 2014). The disease is spreading from tropical regions to most subtropical regions of the world, causing human suffering and considerable socioeconomic losses and hence considered as a global public health challenge (WHO, 2012).

The Asia- Pacific region carries 70% of the global burden of disease whereas 1.3 billion of at-risk individuals live in ten dengue-endemic countries in South-East Asian Region (SEAR) (WHO SEARO, 2011; Bhatt et al., 2013; Stanaway et al., 2016).

Being a tropical island in the SEAR, Sri Lanka has experienced the Dengue disease, initially as sporadic cases and later on as epidemics, covering more geographical areas of the country. The first serologically confirmed dengue case was reported in 1962 whereas the endemicity of the disease was declared in mid-1960 (Vitharana & Jayakuru, 1997). The severe forms of Dengue virus infection (DHF and Dengue shock syndrome (DSS) were only sporadically reported before 1989 (Sirisena & Noordeen, 2014). However, frequent emergence of epidemics with more severe forms of the disease and detection of all four virus serotypes has now led Sri Lanka to be categorized as a hyper-endemic country (WHO, 2019). The country experienced the largest ever Dengue outbreak in 2017 recording 186,101 cases (833.9 per 100,000 mid-year population) and 440 deaths (Case Fatality Rate: 0.24) (Epidemiology Unit, 2019).

Dengue surveillance and integrated vector management (IVM) were identified as the mainstay of prevention and mitigation of Dengue outbreaks. IVM is defined as “a rational decision-making process for the optimal use of resources for vector control”. Collaboration within the health sector and with other sectors through the optimal use of resources, planning, monitoring and decision-making was identified as one of the key elements for the successful implementation of IVM (WHO, 2019).

Considering the epidemic nature of the disease, more proactive strategies were identified on the prevention and control of Dengue and practised widely after 2009 dengue epidemic. Stakeholder groups were identified based on the evidence generated by the Dengue disease surveillance, entomological surveillance, and door to door premise inspection programmes. A presidential task force was formed to interlink health with the other stakeholder ministries. Preventive activities were coordinated by the engagement of all stakeholders. However, this was not so intensified and was not monitored regularly until 2017 major Dengue outbreak.

2 Objectives

This analysis aims to evaluate the outcomes of stakeholder engagement in Dengue control after implementation of intensified interventions during 2017 major Dengue outbreak by comparing relevant premise inspection and vector surveillance data for the year 2017 and 2018.

3 Methods

A desk-based review was conducted to describe the premise inspection surveys and entomological surveillance data to explore the sustainable engagement of key stakeholders in dengue control in Sri Lanka.

With the emergence of 2017 Dengue outbreak, interventions towards stakeholder engagement were strengthened and monitored stringently by the Presidential Task Force (PTF). Following key interventions were adopted.

1. Reformation of Multi-stakeholder accountability framework
2. Implementation of Integrated actions via multi-stakeholder engagement
3. Launching of widespread communication campaigns to empower stakeholders.

Each stakeholder ministry is accountable for the control activities in the premises under their purview. The Ministry of Education is accountable for schools, the Ministry of Local government for public places, and the Ministry of Housing and Construction for construction sites etc.

Following were the interventions implemented.

3.1 Reformation of a Multi-stakeholder Accountability Framework

The Presidential Task Force (PTF) was re-convened, and multi-stakeholder accountability framework was reformed to intensify prevention and control of dengue through a comprehensive integrated approach. "Intensive Integrated Action Plan" which included the mandate and activities of respective ministries for the elimination of mosquito breeding places within institutions was developed, distributed and their actions were monitored by conducting regular PTF meetings chaired by the Secretary to Hon. President. Major ministries which were either contributed to the outbreak and needs regular monitoring or could extend their support directly or indirectly to mitigate the outbreak were invited as the stakeholders (Fig. 1).

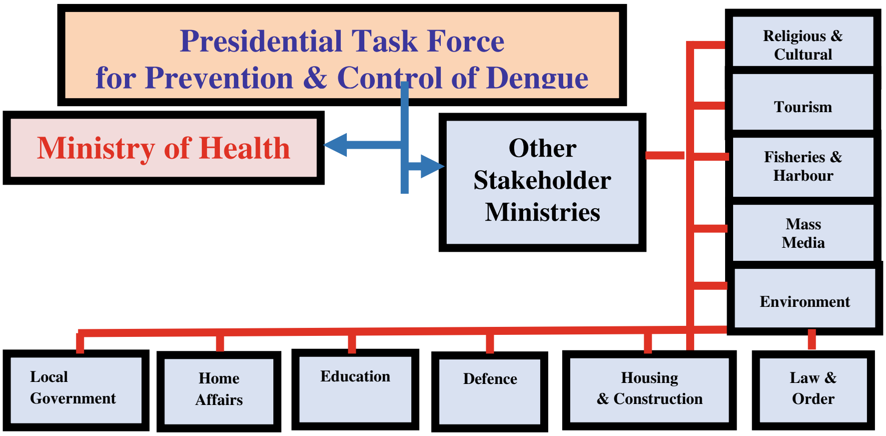

Fig. 1 The organizational structure of the presidential task force for prevention and control of dengue

The inter-sectoral coordination was not limited to the national level but extended up to the provincial, district, divisional and village level involving personals with different hierarchical positions representing health as well as non-health stakeholders. The main aim was to empower people and the stakeholders on sustainable environmental management activities (Fig. 2). The provincial and district coordination committee meetings were held monthly basis while divisional level meetings were held biweekly in high-risk Medical Officer of Health (MOH) areas whereas monthly in low-risk areas. The village/street committees focused on forming street committees in order to carry out environmental management and source reduction at field level.

3.2 Implementation of Integrated Actions via Multi-stakeholder Engagement

National Dengue Control Unit (NDCU), representing the Ministry of Health (MoH), functioned as the focal point of all preventive activities. Specific roles were outlined for each ministry and their active contribution towards Dengue control was obtained as an integrated manner. According to epidemiological, entomological and premise inspection data, schools and construction industries were found to have the highest risk and therefore, actions towards these ministries were intensified more and monitored vigorously compared to other ministries. Some ministries were identified because of their valuable contribution to preventive activities.

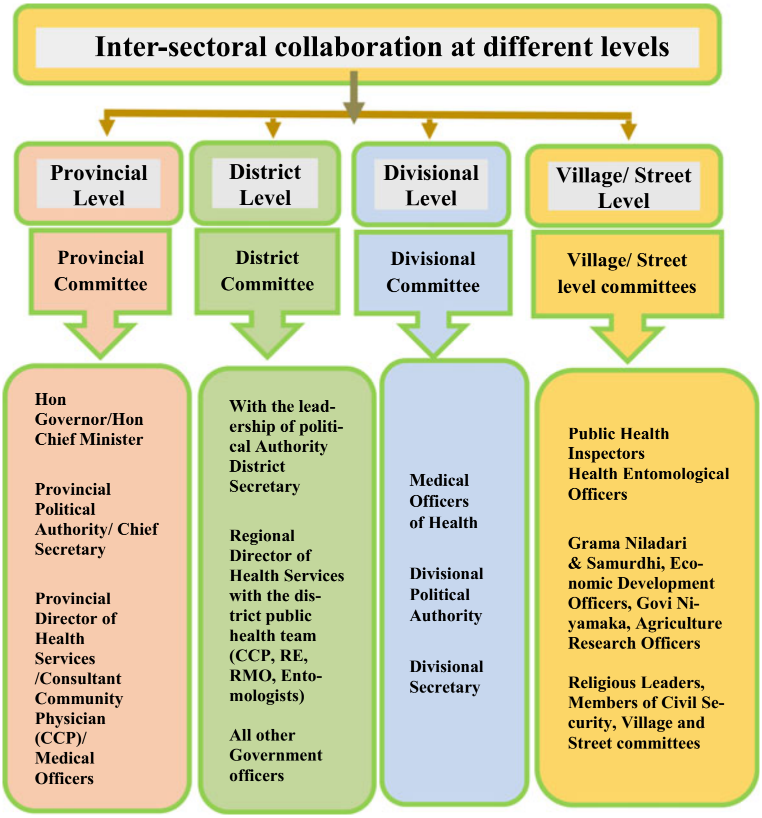

Fig. 2 Inter-sectoral collaboration at the subnational level

- **Ministry of Education**

Schools were focused more as 30% of total Dengue cases was reported among school-going children and considerable breeding places were found in school premises making schools as a more vulnerable locality for the spread of Dengue.

School children were identified as the best change agents. Considering this, school Dengue cards were introduced to schoolchildren with the instruction to complete the card after inspecting their premises. With the emergence of the outbreak, this programme was strengthened and implemented in all high-risk districts. Many curriculum-based activities related to Dengue control were introduced and assessed during the examinations, including national level examinations. Dengue committees were established in schools and school premises were divided into different zones, the responsibility of premise inspection in each zone was given to a dedicated group.

Series of mosquito control programmes were conducted covering schools as high-risk locality. Apart from this, special premise inspection and source reduction programmes were conducted in par with scheduled general examinations and before re-opening of schools after the school holidays with the support of divisional level public health teams. Local public health team also conducted awareness programmes for the students and parents. Guidelines were issued by the Ministry of Health jointly with the Ministry of Education emphasizing specific actions to prevent the spread of Dengue in school premises. Special chemical control measures were introduced into the school sector. All these activities were strictly monitored at national and subnational level via regular inter-sectoral meetings.

- **Ministry of Housing and Construction**

Interventions towards construction sites were introduced in the designing stage, construction stage and maintenance stage with a special focus to the second stage. Although the Ministry of Housing and Construction is the main stakeholder, many other organizations also involved in strengthening the entire process. Sri Lanka Institute of Architect, The Association of Consulting Engineers Sri Lanka (Aces), Lanka Association of Building Services Engineers were identified as the main stakeholders of the first stage and primarily focused on environmental modification practices during the designing which minimize rainwater collection thereby preventing vector mosquito breeding.

The most challenging stage to handle was the construction stage which created a very conducive environment for mosquito breeding due to generation of discarded non-degradable materials, utensils, equipment which could collect either greywater or rainwater. NDCU together with Construction Industry Development Authority (CIDA) carried out many activities to engage the responsible personals of this industry on the prevention of Dengue. Registration of construction sites under Local Government and divisional public health authority was made mandatory. A guideline was developed on how to maintain the construction premises and the specific roles and responsibilities of the team on the prevention of Dengue. A series of capacity building programmes were held to train contractors and safety officers on the prevention of mosquito breeding places. The teams were trained on environmental manipulation practices, solid waste management, regular housekeeping, and source reduction. All construction sites were advised to appoint a housekeeping crew in each site and weekly premise inspection was made mandatory. All findings during the weekly inspection were recorded in the premise inspection card developed by the NDCU. According to the mandate, all inaccessible breeding places should be notified to divisional public health authorities in order to implement either source reduction or chemical control. Specific chemical control measures which are suitable for construction sites were introduced. All construction sites were instructed to compile a monthly premise inspection report to be sent to the divisional public health authority in the respective area.

- **Coordinated actions with other stakeholder ministries**

Many more activities were carried out in collaboration with other stakeholders. The **Ministry of Local Government (LG)** engaged in the planning and implementation of island-wide solid waste management programmes. The "Latta-lotta" programme which mainly targeted collection of non-degradable solid waste and subsequent selling of recyclables was implemented in most of the high-risk localities apart from routine solid waste collection programmes. The **Ministry of Home Affairs** extended the support by involving administrative personals in the district, divisional and "grama niladharee" (village level) levels in dengue control activities. The responsibility of premise inspection of government institutions was also taken by the ministry. Support of the teams attached to the divisional secretary office was obtained for special premise inspection programmes. The **Ministry of Defence** provided the necessary human resource for mosquito control campaigns. Series of special premise inspection campaigns with extensive mobilization of tri-forces (rapid response teams for each district) were carried out in high-risk areas targeting all premise types. Nearly 3 million premises were inspected in 2017 and this cost around USD.800000 (Tissera et al., 2020). Extensive mass media campaigns were organized by the **Ministry of Mass Media** for community empowerment and social mobilization. Risk communication was carried out through print and electronic media. Selected time slots during peak and off-peak hours were dedicated for community education and awareness. Coordinated activities were carried out with the **Ministry of Religious and Cultural Affairs** to obtain their active contribution to source reduction in religious places. The religious leaders engaged in community education and awareness programmes and in the process of forming village committees. The **Ministry of Fisheries and Habour** is one of the main stakeholders as fishing boats and harbours were found to have a considerable number of breeding places. Specific measures towards the reduction of breeding sources in these sites including chemical control methods were implemented and supervised regularly by the public health teams. The **Ministry of Tourism** was incorporated as a stakeholder to ensure the hotels and other recreational areas are free of mosquito breeding in order to sustain the tourism industry. The **Ministry of Law and Order** extended the support by providing human resource for field programmes and application of legal enactments for Dengue control. The **Ministry of Environment (MoE)** engaged in providing inputs and expert opinion in protecting the ecosystem in implementing Dengue control strategies especially during the introduction of biological and chemical vector control measures.

3.3 Launching of Communication Campaigns

Widespread communication campaigns were launched during the outbreak period to empower the community and other stakeholders on sustainable Dengue control and to instil early treatment-seeking behaviour. Main media organizations dedicated times-lots from airtime to promote social mobilization. Regular media updates were issued to strengthen community awareness and support towards environmental management practices as well as to prevent any undue fear psychosis among the masses. Eminent clinicians, public health experts, scientists, researchers as well as other stakeholders were regularly featured in programmes and discussions disseminating the true facts and figures.

Considering schools and construction sites as the priority sites, special IEC materials were developed and displayed in these localities. Posters were put up with stringent inspections and litigations carried out at such construction sites. Large-scale constructions where foreign (ex. Chinese, Indian) workers are involved were especially targeted with posters and handouts being prepared in foreign languages. Development of a mobile application for the community to report potential breeding habitats and improved community awareness through text messages on prevention and control of Dengue could be named as innovative strategies for Dengue control at this juncture. The whole social marketing campaign cost around USD 98,000 during 2017 outbreak for the MoH apart from the sponsorship granted by the other media organizations.

4 Results

Impact of stakeholder engagement was measured by using premise inspection data gathered via door to door Special Mosquito Control Campaigns (SMCCs) in 2017 and 2018. Altogether 19 and 13 SMCCs were conducted covering 2.7 million and 1.4 million premises in 2017 and 2018 respectively. Of them, 20 and 21% of premises reported to have potential breeding places and 1.98 and 2.29% of premises were reported to have larvae positive in respective years. This showed an overall increase in potential and positive breeding places in 2018 compared to 2017.

Detailed inspection of these premises has resulted in an increase in the detection of potential breeding places in the majority of premise types in 2018 compared to 2017. Schools showed an increase of 23%, from 35.5 to 58.7% while construction sites showed an increase of 13.4% from 41.1 to 54.5%. Government institutions and houses showed the least increase whereas public places showed a reduction in potential breeding places in 2018 compared to 2017 (Table 1).

The summary of larvae positive breeding places by different types of premises also revealed that the majority of premise types were found to have more larvae positive places in 2018 compared to 2017 (Table 2). This was reflected largely in schools and construction sites showing an increase of 6.5% and 3.8% respectively (from 5.3 to 11.8% in schools; from 5.8 to 9.6% in construction sites). However, public places showed a reduction in larvae positive breeding in 2018 compared to 2017.

When island-wide entomological survey results in 2017 and 2018 were compared, this showed an increase in premise index (PI) in 13 districts out of 26 districts and ranged from 1.9% (Ampara) to 109%. (Kegalle). However, the Western Province which bears the majority of Dengue burden showed a decline in PI in 2018 compared to 2017 (Table 3). Further, the outcome of stakeholder engagement was mirrored in entomological surveys, mainly in schools and construction sites in 2017 and 2018 as in premise inspection programmes (Tables 3 and 4).

Table 1 The summary of potential breeding places by type of premise in 2017 and 2018 (*Source:* National Dengue Control Unit, Sri Lanka)

Premise type	2017 (%)	2018 (%)	Difference
Houses	20.1	21.8	1.7
Schools	35.5	58.5	23
Other educational institutes	22.9	29.2	6.3
Government institutes	28.2	28.6	0.4
Private institutes	25.9	25.9	0
Factories	31.0	40.9	9.9
Construction sites	41.1	54.5	13.4
Religious places	34.4	37.3	2.9
Public places	31.3	24.9	−6.4
Other places	30.0	28.0	−2

Table 2 The summary of larvae positive breeding places by type of premises in 2017 and 2018 (*Source:* National Dengue Control Unit, Sri Lanka)

Premise type	Year		
	2017	2018	Difference
Houses	1.9	2.2	0.3
Schools	5.3	11.7	6.4
Other educational institutes	2.4	4.3	1.9
Governmental institutes	4.1	5.1	1
Private institutes	3.2	3.2	0
Factories	5.5	7.4	1.9
Construction sites	5.8	9.6	3.8
Religious places	4.2	6.5	2.3
Public places	3.3	2.4	−0.9
Other places	2.0	2.1	0.1

5 Discussion

Sri Lanka's public health infrastructure which strategically implements all preventive activities related to Dengue extends from the national level to the grass-root level. Being a disease that needs dedication and commitments beyond the health sector to control, Ministry of Health has collaborated with many stakeholder ministries under the purview of Presidential Task Force to implement integrated Dengue control activities Island wide. National and sub-national inter-sectoral coordination spearheaded the multi-stakeholder contribution towards Dengue control up to community level. This was at its best during the 2017 dengue outbreak, the largest ever outbreak recorded in Sri Lankan history. Many integrated interventions were launched during this year and continued. Parallel to this, intensified mass media campaigns were deployed throughout the island to empower the community and to mobilize all stakeholders towards sustainable Dengue control.

Table 3 The larval entomology surveys by district in 2017 and 2018 (*Source:* National Dengue Control Unit, Sri Lanka)

District	2017 (PI)	2018 (PI)	Difference	% difference
Colombo	8.0	7.9	−0.11	−1.3
Gampaha	11.0	9.3	−1.74	−15.8
Kalutara	12.2	11.2	−1.00	−8.1
Polonnaruwa	9.4	8.1	−1.35	−14.3
Anuradhapura	11.3	12.4	1.07	9.4
Badulla	12.2	8.6	−3.64	−29.8
Moneragala	7.8	11.7	3.90	49.7
Batticaloa	13.6	11.0	−2.59	−19.0
Kalmunai	4.7	6.0	1.26	26.6
Trincomalee	7.9	6.8	−1.12	−14.1
Ampara	6.6	6.7	0.11	1.6
Galle	9.3	8.1	−1.26	−13.5
Matara	14.8	14.2	−0.63	−4.3
Hambantota	7.8	11.4	3.57	45.6
Kandy	12.3	13.5	1.16	9.5
Matale	5.6	4.9	−0.72	−12.8
Nuwara Eliya	5.2	4.7	−0.44	−8.6
Jaffna	9.9	9.4	−0.52	−5.2
Kilinochchi	3.0	4.9	1.83	60.2
Mullativu	5.7	7.2	1.55	27.2
Vavuniya	5.1	5.1	0.04	0.8
Mannar	12.0	11.9	−0.03	−0.2
Kurunegala	7.4	9.5	2.03	27.4
Puttalam	8.9	12.9	4.00	44.9
Rathnapura	8.1	8.5	0.39	4.8
Kegalle	7.8	16.4	8.58	109

Table 4 The summary of larval entomology surveys by premise type in 2017 and 2018 (*Source:* National Dengue Control Unit, Sri Lanka)

Entomology surveys				
	Construction sites		Schools	
Year	Number inspected	No of Larvae positive places (%)	Number inspected	No of Larvae positive places (%)
2017	301	46 (15)	284	156 (55)
2018	146	38 (26)	237	123 (52)

Despite all interventions carried out in 2017 through inter-sectoral collaboration, 2018 premise inspection data revealed a comparatively higher number of potential and positive breeding places in relation to 2017. This was further evidenced by the entomological surveillance indicating higher PI in 13 out of 26 districts in 2018 compared to 2017 and with high larval positivity rate, especially in schools and construction sites.

This could also be an outcome of quality premise inspection by the 1300 field workers recruited in 2017 as they were trained for premise inspection. Reduction in breeding places in public places shows that interventions with LG have worked well. However, a considerable increase in potential and positive breeding places in schools and construction sites regardless of all interventions warrant innovative policy decisions to overcome the challenging situations in the educational sector and construction industry. The negative outcome in the subsequent year could be a result of lost sustainability of interventions and commitment by the non-health stakeholder as the monitoring pressure waned off in the absence of a major outbreak.

6 Conclusion

Regardless of the presence of Dengue outbreaks in a country, inter-sectoral coordination should be strengthened over the years to produce favourable results on Dengue control. In parallel, innovative strategies leading to the behavioural impact of the stakeholders and continuous monitoring are mandatory for the establishment of sustainable Dengue control by stakeholders.

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Knowledge, Reported Practices and Their Associated Factors on Disaster Preparedness Among Residents of MOH Area, Agalawatta, Sri Lanka

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Abstract Agalawatta is a natural disaster-prone area in Kalutara district which has a uniform weather pattern with seasonality. A descriptive cross-sectional study was conducted among aged 15–59-year-old permanent residents in Agalawatta Medical Officer of Health area to assess the knowledge, reported practices and their associated factors of disaster preparedness. Interviewer administered questionnaire was used to ascertain data. A knowledge score was developed based on questions on different aspects of knowledge on disasters and disaster preparedness. Majority of the respondents found floods (72.9%, n = 436) and landslides (67.1%, n = 401) as the most commonly occurring natural disasters in Agalawatta. Only 16.2% (n = 97) of the study population was having more than the middle value of the knowledge score (i.e. 45 out of 90). Participants with previous experience in natural disasters had higher knowledge compared to those who were not (58.7% vs. 41.4%, $p < 0.01$). Only, 17.9% (n = 107) of the population identified "divisional focal point" as a stakeholder who needs to contact during a disaster and 33.3% (n = 199) of the study population has identified a potential safe location to move during a natural disaster in the area. Those who have experienced previous disasters were having higher knowledge and favorable practices than who haven't experienced a disaster.

Keywords Disasters · Disaster preparedness · Floods · Landslides

1 Introduction

Disaster is a sudden extreme event, which causes great damage to all living beings, especially the human beings. It occurs rapidly and simultaneously, where natural or man-made induced scenarios would exceed its optimum tolerable limit. Hence,

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resulting loss of property, livelihood with injury and loss of lives. Irrespective of the population context of being rural or urban, disasters do occur following natural hazards or man-made hazards (Sandrock, 2003).

The World Health Organization (WHO) defined disasters as "events that occur when significant numbers of people are exposed to extreme events to which they are vulnerable, with resulting injury and loss of life, often combined with damage to property and livelihoods" (Sandrock et al., 2003).

Few words such as "hazards", "vulnerability", "capacity" and "risk" are frequently used terms to explain the disaster situations.

"Hazards" can be defined as "a dangerous condition or event, that threat or have the potential for causing injury to life or damage to property or the environment" (Technology, 2008). These are categorized into natural and manmade causes. Hazards with meteorological and geological origin are mainly causing natural hazards such as earthquakes, cyclones, Tsunamis, etc. Hazards such as landslides, floods, droughts are known as socio-natural hazards since their causes are both natural and manmade (Technology, 2008).

"Vulnerability" can be defined as "the extent to which a community, structure, services or geographic area is likely to be damaged or disrupted by the impact of particular hazard, on account of their nature, construction and proximity to hazardous terrains or a disaster prone area" (Technology, 2008).

"Capacity" can be defined as "resources, means and strengths which exist in households and communities and which enable them to cope with, withstand, prepare for, prevent, mitigate or quickly recover from a disaster" (Technology, 2008).

"Risk" can be defined as a "measure of the expected losses due to a hazard event occurring in a given area over a specific time period and function of the probability of particular hazardous events and the losses it would cause" (Technology, 2008). These can be categorized into physical and socio-economic vulnerability. The objects which are affected and extent of the damage is known as the physical vulnerability while the intensity of socio-economic impact is known as the socio-economic vulnerability.

The level of risk depends on the nature of the hazard and the vulnerability of the affected. Thus, all the measures which reduce the disaster related losses by reducing the hazards and the vulnerability are called as disaster risk management. This is best explained as in the form of a cyclic process called disaster management cycle. The basic concepts of disaster management cycle can be explained in several stages (Fig. 1).

2 Contexts on Disasters

According to the worldwide disaster analysis, reasonable amount of damages and consequences are reported globally where large variations are being reported across regions, countries, diversed socio-economic backgrounds and even between genders (Suvit, 2001). During 1976–2005 period, Asia shares 41% of global floods which has accounted 65% of deaths and 96% being affected from it. Furthermore, South

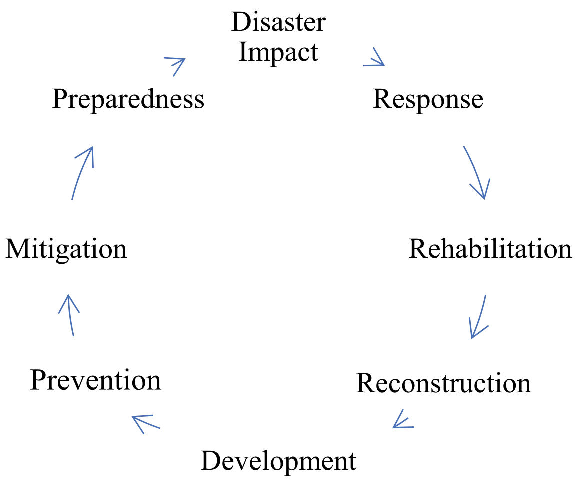

Fig. 1 The disaster management cycle (Adapted from Technology, 2008)

Asia accounts for 33% of the floods in Asia, 50% of those killed and 38% being affected (Shrestha, 2008).

Plenty of studies have been published relevant to disaster preparedness. Storage of food and water, securing the furniture high, establishing household emergency plans has minimized the damage to households and has developed their coping strategies as well (Paton, 2003). Nevertheless, many developments have taken place in disaster preparedness internationally and locally in the recent years especially after the Tsunami in December 2004. United Nations Development Programme (UNDP) began to develop a Sri Lankan disaster database in 2003 which include both natural and technological disasters (Tschoegl et al., 2006). According to the data base, most common types of disasters are animal attacks, fire, floods, extreme wind events and lightening. Tsunamis were not listed in the disaster profile until the 2004 Tsunami. The revised disaster database of Deslnventar revealed in 2016 that the most frequent natural disaster in Sri Lanka is flood (37%) followed by strong wind, landslide and cyclone (Japan International Cooperation Agency, 2017). Furthermore, it revealed that landslides cause most deaths and missing people followed by flood, extreme winds and lightening. Floods accounts nearly 50% of livelihood damages and 2008 cyclone with floods resulted the highest number of livelihood damage in the eastern part of Sri Lanka, resulting an overall 80% of flood from the total natural disasters (Japan International Cooperation Agency, 2017).

According to the JICA (Japan International Cooperation Agency) survey report 2017, there has been clear correlation of disaster occurrence with the rainy weather pattern, where the highest amount of people are being affected from floods and extreme winds during the south-west monsoon period in May–June and the north-east monsoon period in November-January. High seasonal rainfall from south-west monsoon may cause destabilization in the heavy monsoon affected mountain areas and may cause frequent landslides too (Japan International Cooperation Agency, 2017). Agalawatta MOH area lies in Kalutara district in Sri Lanka which receives heavy rainfall throughout the year with average rainfall of nearly 1000 mm (World weather online, 2020) thus known as a high natural disaster prone area.

A road map for disaster management in 2005 was prepared to minimize the adverse effects of hazards via preventive and adequate measures to ensure better delivery of relief and necessary assistance following disasters (Disaster Management Center, 2005). Preparedness activities including testing of warning alerts, evacuation and safety measures, development of operational plans was supported through the provision of the Disaster Management Act. Key interventions of this road map have been to develop comprehensive action plans for disaster management at the national, sub national and local levels involving related multi stakeholders. Thus, identification of the competent focal points in emergency and disaster management at all levels was important.

3 Methodology

3.1 Study Design and Setting

A descriptive cross sectional was conducted in Agalawatta Medical Officer of Health (MOH) area. According to the Census and Statistics of 2012, the total population of the area was 36,669 and 15–59 year age population was 21,937 (Department of Census and Statistics, 2012). Table 1 gives the population distribution of Agalawatta MOH area. The MOH area is consisted of 34 Grama Niladari (GN) divisions. Majority are Buddhist Sinhalese living in rural sector (Table 2).

3.2 Study Participants

Study population was considered as residents aged 15–59 years in MOH area, Agalawatta. The age group from 15–59 years is known as the working age population (Siddhisena, 2005); in general they are financially engaged and involved in decision making. Thus, it is expected this group would be the most active during a disaster

Table 1 Population, age and sex in Agalawatta divisional secretariat

	Age (in years)									
Sex	15–19	20–24	25–29	30–34	35–39	40–44	45–49	50–54	55–59	15–59
Male	1363	1142	1196	1445	1217	1160	1063	982	978	10,546
Female	1349	1280	1336	1513	1263	1288	1104	1111	1147	11,391
Total	2712	2422	2532	2958	2480	2448	2167	2093	2125	*21,937*

Source Department of Census and Statistics (2012)

Table 2 Population distribution of MOH area Agalawatta according to ethnicity, religion, and sector

Ethnicity	Total
Sinhala	36,655
Indian Tamils	802
Sri Lankan Tamils	122
Moors	69
Religion	*Total*
Buddhists	35,475
Hindu	782
Christians and Roman Catholics	328
Islamic	84
Sector	
Rural	35,344
Estate	1,325

Source (Department of Census and Statistics, 2012)
Data was collected over six weeks from 3rd of August to 14th of September 2015

and having the overall responsibility in preparing for disasters in the area. Residents (aged 15–59 years) of MOH area, Agalawatta who are permanently living for 2 years or more from the data collection date were included for the study thus, people with mental illness who will not be able to give valid information and those who were not given the consent were excluded. With considering the population size of Agalawatta MOH and sampling method, the estimated sample size was 630.

Out of the 34 GN divisions in the Agalawatta MOH area, 30 housing clusters were selected by probability proportionate to the size (PPS) of number of households in each GN divisions. Only one eligible person was recruited from a household. If more than one eligible person was present at a household, the participant was selected randomly using a Kish selection table (Goodman & Kish, 1950). Households were visited during evenings of weekdays. When selected subjects were unable to interview, they were visited again in a pre-scheduled time convenient for participants including the weekends. This was helped to increase the response rate.

3.3 Measures

Pretested interviewer administered questionnaire was used. Questionnaire initially developed in English language and translated to Tamil language too. Content of the questionnaire was decided with referring to previous studies and textbooks. This questionnaire was divided into three sections as (1) socio demographic details, (2) knowledge on disaster and preparedness and (3) reported practices on suspecting a disaster and practices during and after disasters.

Data collectors were selected based on their educational qualifications (i.e., three passes in advanced level in science stream), living in the same MOH area with good rapport familiar with the area and either one of them needed to be fluent in Tamil language. Workshop was conducted for the data collectors prior the study on several components as (1) introduction about disasters with detailed description, (2) ethical aspects, (3) communication skills, and (4) step by step description to the questionnaires. Role plays were conducted to improve the confidence of administering the questionnaire and ensure their competency in administering the questionnaire efficiently.

3.4 Procedure

The study was carried out in accordance with the ethical clearance from Ethics Review Committee of National Institute of Health Science (NIHS), Kalutara and administrative clearance from Provincial Director of Health Services—Western Province, Regional Director of Health Services, Kalutara and Divisional Secretariat, Agalawatta. In the first contact with the potential participants, an information sheet was provided with all necessary information and opportunity was given to ask questions. Participants was informed that they have right to withdraw from the study at any time during the interviews without giving any reasons. Informed written consent was obtained prior to administer the questionnaire. The researcher ensured that the study was conducted with minimum interference to the routine activities of the stakeholders and the participants. The study did not involve any invasive procedures or not questioning on socially unacceptable information. Thus, it was expected to have minimal harm to the participants. However, since the questionnaire had the questions relevant to the disasters, interviews may have led to remind the previous disaster situation/personal experiences. Therefore, interviewers were given adequate knowledge to face such situation and they were instructed to contact the principal investigator of the study immediately to take necessary steps base on the situation. Confidentiality of data collected was strictly adhered and the anonymity of the participants was maintained as well. At the end of the study, several awareness programs were organized at community level which addressed the knowledge gaps of the study participants. The study will be a great importance plan future awareness programs and finally to minimize the impact of disasters to human health in the Agalawatta MOH area.

4 Data Analysis

All the socio-demographic characteristics except the employment status were categorized according to the method used in Demographic Health Survey (DHS). Socio-demographic characteristics were reported as frequencies and percentages. Characteristics were categorized appropriately. Knowledge was divided into two sections.

Those were (1) Knowledge on disasters and (2) knowledge on disaster preparedness. Responses to questions were presented as "yes", "no" and "don't know". These answers to each question on disasters and disaster preparedness were presented with frequencies and percentages. "Incorrect" and "don't know" responses were given a score of "0". The response "don't know" was given the "0" marks as the respondents had no idea about the answer. One mark was given for each correct response. The total cumulative score for all the knowledge-based questions ranged from "0" to "90". Middle value of the score (i.e., 45) was used to analyze the proportion of population having at least 50% of the expected knowledge from the questionnaire. Population was divided into two groups as (1) poor knowledge and (2) good knowledge based on the median value of the distribution of reported cumulative scores of the study population. These two groups were used to assess the association between knowledge and different socio-demographic characteristics and practices (Table 3).

Analysis of questions regarding reported practices and factors associated with knowledge and reported practices on disaster preparedness were considered as frequencies and percentages. Nevertheless, a score was not developed from different practices as they are diverse and need to consider individually. Compiled overall knowledge score was compared with reported practices and previous experience in disasters as well. Significance level was considered as <0.05.

Table 3 Key areas considered under the knowledge on disasters and knowledge on disaster preparedness

	Knowledge on disasters	No of questions
1	Commonly occurring natural disasters	1
2	Natural disasters commonly occurrence periods	1
3	Consequences/losses of natural disasters	1
4	Causes of flood occurrence	1
5	Causes of landslide occurrence	1
6	Landslide prone areas	1
7	Human effect on natural disasters	1
	Knowledge on disaster preparedness	
1	Identified risk areas on natural disasters	1
2	Early signs for floods	1
3	Early signs for landslides	1
4	Minimize home hazards from floods	1
5	Minimize home hazards from landslides	1
6	Evacuation measures regarding natural disasters	1
7	Safe locations regarding natural disasters	1
8	Contacts with community	1

Table 4 Distribution of knowledge score on natural disaster preparedness in Agalawatta medical officer of health area

Knowledge score	Frequency	Percentage (%)
Knowledge score of 45 or more	97	16.2
Knowledge score less than 45	501	83.8
Total	598	100.0

5 Results

A total of 630 participants were selected to the study. Out of them, 598 interviews were completed successfully (Response rate = 95%). The mean age of the respondents (age 15–59 year) was 37.55 years with a standard deviation of 10.96. Most of the population knew that floods (72.9%, n = 436) and landslides (67.1%, n = 401) are occurring in the area. Majority of respondents claimed that human activities influence on floods (65.9%, n = 394) and landslides (68.4%, n = 409). About 52.3% and 50% of the study population was having an understanding on the mode/method to reach a safe location on floods and landslides respectively. Nevertheless, less amount of respondents further knew that safe location should be a place that is easily reachable (33.3%, n = 199), a reachable place for helping agencies (27.1%, n = 162), has adequate space to stay during disasters (21.9%, n = 131) and having adequate sanitary facilities (13%, n = 78). Majority of the study population claimed that Grama Niladari (84.4%, n = 505) and area Public Health Midwife (79.9%, n = 478) are contactable stakeholders as divisional focal point during a disaster situation.

The knowledge was categorized in to two groups considering the middle value (i.e., 45) of the total knowledge score (i.e., 90) developed from the knowledge-based questions (Table 4).

Only 16.2% (n = 97) out of the study population have a “Knowledge 45 or more” about disaster preparedness in Agalawatta whereas majority (83.8%, n = 501) have a “Knowledge less than 45”.

Only 39.6% (n = 237) have experienced any disasters during past 10 years thus about 72% (n = 170) of the study participants reported to have consumed food which were recommended only by area health officials. Majority 158 (66.7%) drank bottled water only which showed a significant association ($p < 0.05$) between overall knowledge with drinking only bottled water. Association between overall knowledge with previous experience in natural disasters had significant association ($p < 0.01$) as shown in Table 5.

6 Discussion

In Sri Lankan context, limited numbers of studies have published on frequently occurring natural disasters in disaster prone vulnerable localities. Present study was timely conducted in one of the vulnerable areas in District of Kalutara. Perhaps this study provides information and guidance for future disaster preparedness plans

Table 5 Association between overall knowledge with previous experience in natural disasters

With previous disaster experience	Good knowledge, n (%)	Poor knowledge, n (%)	Total, n (%)	Significance[a]
Yes	212 (58.7)	149 (41.3)	361 (100)	$\chi^2 = 17.301$ $p = 0.001$
No	98 (41.4)	139 (58.6)	237 (100)	
Total	310 (51.8)	288 (48.2)	598 (100)	

[a]Degree of freedom is 1 in all cross tabulations

of the area. Questionnaire was face and content validated prior to use. Interviewer administered questionnaires are considered to be one of the best options to assess the knowledge of particular issue in a community especially related to natural disasters (Hopkins & Warburton, 2015). The best method of assessing a practice needs the observation of the practice in natural environment; since it not feasible to observe the practice in the natural environment, self-reporting of the practices was considered in this study.

According to the present study, considerable proportion of people knew about the factors which result in these natural disasters. A Ethiopian study found that increase in floods was driven mainly by climate change and changes in land use, specifically deforestation (Abaya et al., 2009). In the present study, majority of the population consider that the landslides (68.4%, n = 409) and floods (65.9%, n = 394) are triggered by human activities. This may due to the awareness through the electronic media, school curriculums and their own experience. A study in United Kingdom revealed that awareness of living in a flood risk area had an increased likelihood of being knowledgeable about preparedness, especially about emergency plans ($p < 0.05$) and adopting protecting behaviors ($p < 0.05$) (Coulston & Deeny, 2010). Similarly, present study reported significantly higher knowledge when they have experienced a disaster with past 10 years. A study conducted in Malaysia which assessed the community readiness towards major disasters such as floods and landslides revealed the importance of adequate knowledge in community preparedness (Dorasamy, 2013). Present study reported that heavy continuous rain more than a day (88.5%, n = 529) and rising levels of natural streams (63.9%, n = 382) were the mostly known early signs of floods, whereas tilting or cracking of concrete floors and foundations (60.5%, n = 362) and rapid increase in creek water levels possibly accompanied by increased turbidity (soil content) (55%, n = 329) were the mostly known early signs of landslides. According to a study conducted in United States, 45% of the residents knew about need of evacuation safely and nearly half of the study population were aware about emergency items (i.e. safe food, water bottles and emergency phone numbers) (Redlener et al., 2008). Further, present study revealed that 43.3% (n = 259) of the study population have already identified relevant a safe location while 33.3% (n = 199) knew it should be easily reachable for them.

Only about 18% of population claimed that the divisional disaster focal point should be contacted during a disaster. This shows that the GN and PHM are well popular in the community level as important government servants. Not aware of the disaster focal point should be considered in the future awareness programs. This may probably due to it is being a comparatively new development in the disaster preparedness activities of the government. A previous cross sectional study with regard to knowledge on disasters revealed overall good level of 26%, average 46% and below average being 28% among grade 10 students of Soranathota educational zone in Badulla district (Attanayaka, 2011). Another descriptive cross sectional study on lightning revealed an overall good knowledge level of only 12.4% (n = 62) had "good knowledge" to protect from lightning where most of them (76%, n = 383) had "average knowledge" (Kalubowila et al., 2018). Present study was found that only 16.2% were having the knowledge score more than the middle value (i.e., 45) of the score. A Serbian study done to determine the influence of marital status on citizen disaster preparedness of floods found that there is a significant association ($p < 0.05$) with marital status and knowledge on disaster preparedness. Besides, there was a significant association ($p < 0.05$) with marital status and level of knowledge in this study (Cvetkovic, 2016). Furthermore, a significant association between the having previous experiences in natural disasters and the overall knowledge level thus assume that the previous experience in disaster condition in a previous occasion improve the proper response to a disaster. This rationalize to have "Disaster Drills" and other practical skill developments among communities which help to improve their response during an upcoming disaster.

Our study is having several limitations. This is a community based descriptive cross-sectional study conducted within the MOH area, Agalawatta hence, temporal relationship cannot be evaluated. If the practices on disaster preparedness in a community to be assessed accurately, it is necessary to observe the practice at the actual disaster context. However, it is not feasible in the present study to practically observe the practices, thus the practices were ascertained by questioning. Overall knowledge level was assessed based on the knowledge score developed based on set of questions. Marks were allocated equally for each question. However, there may be certain questions that may important more than the others. Further, knowledge score is not validated. Therefore, the knowledge score may not accurately reflect the knowledge level of the study population. However, knowledge score was used to compare the different categories of the study population. Thus, it could be assumed that analysis of associations is minimally affected.

7 Conclusion

Majority of the population considered floods (65.9%) and landslides (68.4%) are results of human activities thus, about 54% of the study population knew the vulnerable areas prone to floods and 56.0% knew the vulnerable areas for landslides with in Agalawatta MOH area. Grama Niladari (84.4%, n = 84.4) and Public Health Midwife (79.9%, 478) were the mostly contacting stakeholders during a disaster. Nevertheless, only 18% stated that the Divisional Disaster focal point is a stakeholder to be contacted during a disaster. Based on the responses for the knowledge related questions, mean knowledge score for the population was 30.6 and median knowledge score for the population 31.0. Only 39.6% (n = 237) had previous disaster experience hence 35% of the study population was having an experience on flood and 35% of study population was having an experience on landslides. There has been a significant ($p < 0.01$) association between overall knowledge about disaster and "drinking only bottled water during/after the disaster" is significant ($p < 0.01$). Out of the 237 respondents who were having previous disaster experience, 72% consume food were recommended only by area health officials.

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The Relationship Between COVID-19 Preparedness Parameters and its Impact in Developing Effective Response Mechanisms

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Abstract Effectively responding to COVID-19 became the topmost priority of almost all the countries in the world in 2020. The current situation of the COVID-19 has already questioned the Global Health Security and preparedness, as there is a significant deviation between the expected level of pandemic preparedness of countries and their actual performance during COVID-19. In this regard, the identification of reasons behind this deviation is paramount in strengthening pandemic preparedness planning. In this study, a correlation analysis was performed based on data collected from 145 countries from 31st December to 21st May 2020 using SPSS Statistics software, to explore the relationship between the expected level of performance during a pandemic and the level of response in controlling the COVID-19 outbreak. The parameters of expected preparedness levels of countries were extracted from the Global Health Security Index (GHSI), introduced by Nuclear Threat Initiative (NTI) and the Johns Hopkins Center for Health Security (JHU). This tool evaluates the health system, compliance with international norms, and overall risk environment of a country in addition to the fundamental assessment of prevention, detection, and reporting, and rapid response. The results revealed that most prepared countries according to the GHSI, have been affected by comparatively higher damages and the preparedness in 'Overall Risk Environment' has more impact on actual performance in responding to COVID-19. The outcome of the study will help to guide the stakeholders in pandemic preparedness planning to concern more about the overall risk environment and the vulnerability of a country which includes infrastructure adequacy, political risks, and socio resilience and, acquire the effective use of the built environment.

Keywords COVID-19 · Global-health-security (GHS) · Preparedness · Risk environment

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1 Introduction

On 31st of December 2019, a cluster of infected persons with an unknown disease was reported to the World Health Organization (WHO) from Wuhan, China. Later, on 07th January 2020, the Chinese government announced that the source of the disease is a new type of coronavirus, which is currently called SARS-COV-2 or novel coronavirus (WHO, 2020a). Because of the sheer volumes of traveling during the Chinese New Year, the cross-border spread of the virus was very rapid. Thailand was the first country to report the first case outside of mainland China on the 13th of January. Thereafter, cases were reported from Japan, South Korea, and more Pacific Asian countries. The epicenter of coronavirus moved towards the eastern Mediterranean region from China then entered the European continent through Italy. Infected cases in the US started to increase next, leaving a question mark for everyone (WHO, 2020b). According to the numbers reported by the third week of May 2020, there were signs that Brazil will be the next epicenter of the SARS-CoV-2 virus. As of May 21, 2020, more than 5.1 million cases were reported in 213 countries and territories worldwide and 2 international cruise ships with a death toll exceeding 300,000 (WHO, 2020c). Apart from that, the pandemic has caused severe negative impacts on the global economy and social aspects as well (Gormsen & Koijen, 2020).

This situation started to question the global preparedness for pandemics and national health security levels. When investigating the active cases and the number of deaths, it is surprising to notice that the countries which have the highest levels of preparedness according to the evaluation tools such as Joint External Evaluation (JEE) and Global Health Security Index (GHSI) have reported a large number of active cases and deaths during the COVID-19. Though some of these countries have higher healthcare facilities and infrastructures, they have reported higher case fatality rates as well. Among the available evaluation tools of global health preparedness, the Global Health Security Index (GHSI) is the most recent comprehensive assessment of health security in 195 countries developed by Nuclear Threat Initiative (NTI) and the John Hopkins Center for Health Security (JHU) with the Economist Intelligence Unit (EIU) (Nuclear Threat Initiative and Johns Hopkins School of Public Health, 2019). A clear contrast can be seen between the results of the GHS Index and the actual performance of the countries. Table 1 shows a comparison between the ranks obtained in the GHS Index by a few countries and their infected cases and fatality rates that were reported as of May 21, 2020.

There are several possible reasons suggested by the experts for these variations in the performance against the COVID-19 outbreak. The timeline of the containment measures causes a significant impact on the performance in managing a pandemic outbreak effectively (CDC, 2004). A pandemic outbreak such as COVID-19 is a global threat that has to be managed at national levels. The political leadership of a country could make greater impacts on timely measures against a national-level risk. In this context, the connection between the actual performance level and expected level of preparedness should be analyzed to explore the reasons behind this existing scenario. Within this context, this chapter focuses on the relationships between the

Table 1 GHS Index results and cases per million and case fatality rates reported from a few countries

Country	GHSI rank	Cases per million	Case-fatality rate (%)
United States of America	1	4610	6
United Kingdom	2	3698	14.36
South Korea	9	218	2.3
Japan	21	131	4.82
New Zealand	35	240	1.2
Vietnam	50	3	0
China	51	59	5.49
India	57	86	3.25
Russia	63	2237	0.99
Cuba	110	169	4.19

expected preparedness for a pandemic and the current performance in controlling the COVID-19 outbreak, and the impact of the GHS Index on the individual performance of the countries.

2 Literature Review

2.1 Pandemic History and Lessons Learned

The history of pandemics and epidemics goes back to 3000 B.C. Archeological evidence suggests that an epidemic had decimated a prehistoric village in China which is known as Hamin Mangha (Yonggang & Ping, 2016). Spanish Flu (1918) was the most devastating pandemic in recent history which had caused about 50 million deaths. Mostly young and healthy people were affected by the flu and the disease progression happened rapidly. (Johnson & Mueller, 2002; Patterson & Pyle, 1991; Taubenberger & Morens, 2006). After 1918, there was a major outbreak in 1957–1958, called Asian Flu with its roots in China. The United States alone had a death toll of about 40,000 during the Asian Flu outbreak (Ghendon, 1994). The estimated death toll of the Hong Kong Flu (1968) was 1–4 million. Next significant pandemic outbreak occurred in 1977 as an emergence of the H1N1 virus. It originated again in China and spread around the world mostly affecting people over 20 years old (Ghendon, 1994).

China, Hong Kong, Taiwan, and Singapore were severely affected by the SARS (2003) outbreak which caused about 744 deaths and GDP loss of US $4 billion in Hong Kong (Keogh-Brown & Smith, 2008; Wang & Jolly, 2004). In 2009 a new strain of the H1N1 virus emerged again in Mexico. According to the CDC in the

United States, about 1.4 billion people were infected by the virus across the world, and between (151,700–575,400) people met death due to the virus. The unusual thing regarding the 2009 Flu was mostly the children and young adults were affected and 80% of those who were killed by the virus were younger than 65 (CDC, 2010, p. 1). African Ebola occurred in 2014–2016 was one of the recent pandemics which guided human attention more towards global health security. Guinea, Liberia, and Sierra Leone were severely affected by the virus while fewer cases were reported in the United States, Senegal, and Europe as well (Houlihan et al., 2017). 2816 confirmed and suspected cases were reported during the African Ebola and the death toll was 11,310 as of 10th June 2016 (Garske et al., 2017).

Severe impacts caused by pandemics throughout history had highlighted several areas that need attention:

1. Lack of health care facilities and infrastructures
   The Spanish Flu which is considered as one of the deadliest pandemics in recent history pointed out the importance of health security. Poor hygiene and lack of healthcare facilities in the war field had cost drastic results during the Spanish Flu outbreak (Reid et al., 2004). The importance of access to health care was highlighted during the African Ebola outbreak 2014–2016 too. It had taught about what will happen if the healthcare workers were taken away from the functions of the health system. Restricted access to primary health care caused more deaths than persons decimated by the Ebola virus (Sochas et al., 2017). Moreover, recent pandemics have provoked the world to pay more attention to the preparedness and the readiness of the health infrastructures as well.
2. The time gap between the first preventive measures and the first identified case
   The Spanish Flu started to spread when the First World War was going on. The ability to follow containment measures was considerably low. Therefore, the time gap between the first preventive measures and the first identified case was more than 4 months. This delay in taking preventive measures increased the number of infected people drastically. (Martini et al., 2019).
3. The delays in political mobilization
   The delays in political mobilization had become a major issue in most of the Public Health Emergency of International Concerns (PHEICs) declared by WHO. Recently during the Zika outbreak, the global political mobilization was delayed compared to the H1N1 2009 influenza outbreak. More than 3 months were taken by WHO to declare the pandemic as a PHEIC (WHO, 2016).
4. Effectiveness of quarantine measures
   The Cordon Sanitaire in Monrovia, controlled by the Liberian government became unsuccessful because of the violence and the mistrust developed inside the Sanitaire (Phelan et al., 2020). Hence the containment measures should have the ability to maintain the arising demands of peoples such as logistics, medical equipment, etc. Otherwise, the lack of facilities can lead to physiological impacts on people and maybe end up in violence (Fineberg, 2014).

2.2 *Global Health Security*

2.2.1 Global Preparedness for Infectious Diseases

According to the WHO, "Global Health Security" is defined as prevention, detection, and response to naturally emerging biological diseases (World Health Organization, 2015). International Health Regulations (2005) published by WHO is working as an international law assisting the countries in strengthening their health security. (WHO, 2008). According to the lessons learned from pandemics, most of the countries reevaluated their past performance and revised the national preparedness and response plans. France, Germany, the United Kingdom, and Sweden are such countries which had revised their national preparedness plan after the H1N1-2009 outbreak (Droogers et al., 2019). Researchers were engaged in analyzing the major challenges and voids in pandemic preparedness in developing countries (Oshitani et al., 2008). Furthermore, Ebola outbreak 2014–2016 in Africa provoked the Centers for Disease Control and Prevention (CDC) in the United States to strengthen the preparedness of the healthcare facilities (Bell et al., 2016).

In this process of strengthening global health security, assessing the global and national preparedness in a systematic procedure is critical as it enables to identify the areas which are not well equipped (Oppenheim et al., 2019). Table 2 shows a summary of available assessment tools to evaluate compliance with IHR (2005) and global health security.

Table 2 Assessment tools of global health security

Name	Developers	Remarks	References
Self-Assessment Annual Reporting (SPAR)	World Health Organization (WHO)	Evaluated based on the country self-reporting	World health organization (2018a)
Joint External Evaluation (JEE) tool	World Health Organization (WHO)	Assessment of prevention, detection, and response 49 indicators under 19 technical areas occurs every 4–5 years	World health organization (2018b)
Global Health Security Index (GHSI)	Nuclear Threat Initiative (NTI) and the John Hopkins center for health security (JHU)	In addition to the three sections in JEE, this tool evaluates health system, compliance with international norms and overall risk environment 84 sub-indicators listed under 6 main categories are available in this tool	Nuclear threat initiative and Johns Hopkins school of public health (2019)

2.2.2 Global Health Security Index (GHSI)

The Global Health Security Index (GHSI) has been identified as the first major comprehensive assessment of health security in 195 countries urging the them to implement measurable changes in health security at the national level and enhancing the global preparedness for viral outbreaks. In evaluating the expected level of preparedness of a country, the GHSI differs from the JEE as GHSI consists of additional indicators under health system resilience, compliance with international norms, and risk environment. Thus, GHSI has altogether 6 main categories which consist of 34 items cumulatively (shown in Table 3). This tool covers a wide range of factors affecting global health security from the number of hospital beds available to government effectiveness measured by the EIU Democracy Index (Nuclear Threat Initiative and Johns Hopkins School of Public Health, 2019).

Overall findings of the GHSI reveal that no country is fully prepared to withstand against pandemics and there are gaps to be addressed in all 195 countries. It emphasizes on the lack of preparedness for global catastrophic biological outbreaks, untested capacities of health security, lack of funds for filling gaps in the national preparedness, major political risks, lack of foundational health system capacities,

Table 3 Parameters of expected performance in a disease outbreak top three countries in each index

Indicator	Description	Top 3 countries
Overall GHSI index	The overall score of 6 categories	United States, United Kingdom, Netherlands
Prevention sub-index	Preventing the emergence of pathogens	United States, Sweden, Thailand
Detecting and reporting sub-index	Early detection and reporting for epidemics of potential concern	United States, Australia, Latvia
Rapid Response sub-index	Responding rapidly and mitigation the spread of an outbreak	United Kingdom, United States, Switzerland
Health system sub-index	Resourcefulness and robustness of the health system to treat the infected persons and stop the transmission of the disease to health personnel	United States, Thailand, Netherlands
Compliance with international norms sub-index	Measures, taken in enhancing the capacities at the national level, financial plans to address the gaps, and complying with global norms	United States, United Kingdom, Australia
Risk environment sub-index	Overall risk environment including the political risks and vulnerability in the country to biological risks	Liechtenstein, Norway, Switzerland

inadequate coordination and training of health professionals in more than half of the evaluated countries. These 195 countries are clustered into 3 categories namely, most prepared, more prepared, and least prepared based on the results of the GHS Index. Only 13 countries are considered as the most prepared countries for a global biological disease while another 109 countries fall under the more prepared category with 73 least prepared countries.

2.3 Coronaviruses and COVID-19

Coronaviruses are identified as enveloped non-segmented positive-sense RNA viruses which can be found broadly in humans and other mammals (Richman et al., 2016). Most of the human coronaviruses cause mild symptoms such as a common cold. But sometimes they can evolve into severe diseases such as Middle East Severe Acute Respiratory Syndrome (MERS) and Severe Acute Respiratory Syndrome (SARS) (Donnelly et al., 2019; Shaw, 2006). Most recently discovered coronavirus, SARS-CoV-2 (Severe Acute Respiratory Syndrome Coronavirus 2) affects the human respiratory system causing an acute resolved disease, which is later named as COVID-19 by WHO (WHO, 2020a, b, c, d). Similar to most of the viruses in this family, SARS-CoV-2 is also transmitted between individuals basically by respiratory droplets and contact routes (Liu et al., 2020).

The first cluster of COVID-19 cases was reported in China at the end of 2019. Since then, the virus has affected more than 200 countries and territories worldwide and two international cruise ships (WHO, 2020c). Over 5.1 million confirmed cases have been reported as of May 21, 2020, with more than 300,000 deaths. The numbers show that most of the affected people by the virus are older than 65 years. And the fatality rate among older people is also higher compared to the other age groups (Onder et al., 2020). According to the mortality analysis by John Hopkins University, the case fatality rate is comparatively higher in European countries. Several possible reasons such as differences in the total tests conducted, demography, and readiness of the healthcare facilities, have been suggested related to this variation in the case fatality rates ("Mortality Analyses," 2020).

Other than the health impacts, COVID-19 has caused social, economic, and environmental impacts as well. Researchers have predicted that falls in GPD in some countries can go up even to 15% (Fernandes, 2020). Major losses are predicted in several industries which lead the global economy. The air travel industry has experienced a massive loss as flight cancellations were increased rapidly. Tourism industry experienced a great loss since the quarantine measurements were strictly followed in many parts of the world. Global supply chains were affected, and it reduced the flow of goods around the world. As most of the countries adopted to stay at home policies, possible chances of a recession emerged in developed countries (Financial Times, 2020). In March 2020, the International Monetary Fund (IMF) warned that there will be a global recession as adverse as the 2007–2008 global recession, with a recovery in 2021 (Georgieva, 2020). Oil-dependent countries had to experience a shock as the demand for the oil was decreased with the imposed travel restrictions (Ozil & Arun, 2020). Unemployment emerged as a major issue as the lockdown measures forced to follow stay at home rules. In the United States, more than 30 million people have already filed for unemployment benefits within the last two months ("Employment Situation Summary," 2020).

2.4 Global Response Against COVID-19

As the virus originated in Wuhan, Hubei the timeline of responsive measures taken by the Chinese authorities started with publishing the genome data of the virus. The epicenter of the virus, Wuhan city was put in lockdown in mid-January 2020 as the mass traveling during the Chinese Lunar New Year could pace up the spread of the virus. Strict travel restrictions were imposed across Hubei province in 16 cities affecting more than 50 million people (Shih, 2020). Outbound transportation, by all means, was canceled immediately. A budget of 145 million US dollars was allocated to fund the responsive measures. And also, the Chinese government has given special attention to the healthcare facilities they have. Rapid construction of two hospitals with 2300 beds took place in Wuhan to support existing infrastructures. (Khan et al., 2020). Moreover, scientists took the necessary steps immediately in designing the rapid detection kits and developing a vaccine (Hui et al., 2020).

Countries around mainland China took the initial measures even before their first confirmed cases. Implementing temperature screening systems at the airports and required quarantine facilities were common measures taken by the governments. Enhancing social distancing and slowing down the spread of the virus had been the ultimate goal of these containment measures. One of the significant aspects which can be seen in most western pacific countries such as South Korea and Hong Kong (according to the classification of regions by WHO) is the use of lessons learned by previous pandemics, especially from SARS (2003). As an example, the government of Hong Kong took immediate measurements to increase the manufacture of sanitizers and facemasks inside the country (Po-Wei et al., 2020).

Responding to this outbreak became no more specific to the health sector nor the administration sector. It was considered as a multi-sectorial approach that links different sectors (Xiao & Torok, 2020). According to John Hopkins, Bloomberg School of Public Health when the administration of a country is making decisions related to responsive measures, consultancy of the public health experts has become pivotal. Because the behavior of the complex social systems should be included in the models developed for making decisions (Johns Hopkins University, 2020). The necessity of significant changes in social behavior was considerably high in slowing down a pandemic or epidemic outbreak (Bavel et al., 2020; Stuart et al., 2020). Accordingly, the decisions related to travel restrictions, border closures, the capacity of containment measures, and the continuation of essential services and logistics were taken by the policymakers of the country, based on the recommendations of the experts in the interconnected sectors such as health, finance, and academia.

Table 4 Parameters of performance in the COVID-19 outbreak

Indicator	Description
Number of days taken to go for lockdown	Number of days between the first confirmed patient and imposing domestic travel restrictions
Tests per million	The number of diagnostic tests performed per million
Cases per million	Number of confirmed patients per million inhabitants
Case fatality rate	The ratio between the total deaths and total confirmed cases
Recovery case percentage	The ratio between total recoveries and total confirmed cases
Active case percentage	The ratio between total active cases and total confirmed cases

Many questions emerged, whether the measures taken by most of the severely affected countries became successful in controlling the outbreak as expected. The numbers reported under various performance parameters had considerable differences between the countries. Table 4 shows six parameters that had shown such noticeable variations.

The number of days taken to go for a lockdown since the first confirmed case can vary because of several factors and efficiency in decision making is paramount out of them. Closure of schools and universities, banning public gatherings/events, closure of cinemas, and closure of public transport were also included in the lockdown measures taken by the government authorities of the countries worldwide. These measures were imposed around either the whole country or some states/parts of the country. In this context, number of days between the first confirmed patient and imposing domestic travel restrictions was taken as a parameter (Hale et al., 2020).

3 Research Methodology

In this research data required for the parameters mentioned in Tables 4 and 5 were extracted from reports and documents related to COVID-19 and global health security, published by several global organizations such as John Hopkins School of Public Health and WHO. Scores obtained by each country for the overall GHS index and sub-indexes were available in the final report published by the developers of the GHSI (Nuclear Threat Initiative and Johns Hopkins School of Public Health, 2019). data collection of the 'COVID-19 government response tracker' developed by Oxford University presented the dates of imposing domestic travel restrictions (Hale et al., Hale, Webster, et al., 2020). Daily situational reports published by the WHO were used to collect the number of cases and deaths reported in the 145 countries from December 31, 2019, to May 21, 2020 (WHO, 2020c). Population data required to

Table 5 Summary of data collected for 13 parameters for selected countries (out of 145)

Country	Overall GHS index	Prevention sub-index	Detection and reporting sub-index	Rapid response sub-index	Health system sub-index	Compliance with International norms sub-index	Risk environment sub-index	Days for locks down from first case	Tests per million	Cases per million	Case-fatality rate	Recovery case percentage	Active case percentage
US	83.5	83.1	98.2	79.7	73.8	85.3	78.2	54	40,729	4610	6.00	23.6	70.5
Latvia	62.9	56	97.3	54.7	47.3	51.1	67.2	10	50,109	534	2.21	67.7	30.1
Canada	75.3	70	66.4	60.7	67.7	74.7	82.7	53	36,524	2143	7.52	51.3	41.1
Germany	66	66.5	84.6	54.8	48.2	61.9	82.3	52	42,923	2130	4.61	88.3	7.1
Brazil	59.7	59.2	82.4	67.1	45	41.9	56.2	19	3462	1464	6.49	40.5	53.0
South Africa	54.8	44.8	81.5	57.7	33	46.3	61.8	20	8872	323	1.86	46.8	51.3
Italy	56.2	47.5	78.5	47.5	36.8	61.9	65.5	21	53,635	3770	14.24	59.0	26.7
Greece	53.8	54.2	78.4	44	37.6	49.1	58.2	23	13,816	274	5.84	48.2	46.0
Ireland	59	63.2	78	45.1	40.2	52.8	77.4	27	59,945	4946	6.49	86.3	7.2
India	46.5	34.9	47.4	52.4	42.7	47.7	54.4	52	1973	86	3.49	40.9	56
Chile	58.3	56.2	72.7	60.2	39.3	51.5	70.1	21	22,306	2807	1.01	41.66	57.31
Sri Lanka	33.5	24.2	43	26.4	16.9	41.7	56.7	50	2295	49	0.82	57,025	41.95
Uganda	44.3	42.7	50.3	56.5	11.6	65.4	35.5	10	1793	6	0	41.25	58.75

calculate the cases per million were available at the 'Latest United Nations Population Division estimates' (United Nations, 2019). COVID-19 situational reports issued by individual countries and the worldometer website, updated using individual country reports were used to extract data related to recoveries, active cases, and tests conducted per million ("Coronavirus Update (Live)," 2020).

Data were collected from 145 countries for this study, considering the availability of data for all the 13 indicators presented in Tables 4 and 5. Table 6 shows a summary of data collected for several selected countries. However, there is an uncertainty about whether the exact number of cases and deaths have been recorded in the reports, as most of the countries started reviewing back their number of confirmed cases and deaths at the moment. Pearson's correlation analysis was performed on the collected data set, using the IBM SPSS Statics 2013 software to determine the relationships between each indicator from the selected two scenarios. Since Pearson's correlation method gives information about magnitude of the correlation and direction of the relationship, it was selected for the analysis to elaborate on the relationships between the selected parameters in a more informative manner.

4 Findings

Table 7 presents the results of the correlation analysis between the parameters of expected performance levels (preparedness) and the actual performance in responding to COVID-19 in 145 countries. Several questionable relationships were identified from the results.

(i) Relationships with the number of days taken to impose travel restrictions
There is a moderate positive relationship between the days taken from the first confirmed case to go for lockdown and the GHS indexes. Days taken to restrict domestic travel present a moderate strength of correlation towards *overall GHS Index-rho = 0.564*; *prevention sub-index-rho = 0.533*; *rapid response-rho = 0.537* and *health system-rho = 0.547.* A valid argument emerges here as the most prepared countries are to be capable of making rapid decisions regarding quarantine measures. Countries such as the United States, the United Kingdom, and France which are among the top 20 of the GHSI, took more than 50 days from the first detected case to restrict domestic traveling. Accordingly, a low positive correlation can be noticed between the days taken for lockdown and 'cases per million' (*rho = 0.292*).

(ii) Relationships with morbidity and mortality
Both 'cases per million' and 'case-fatality rate' have low positive correlations with the overall GHS index and other sub-indexes. Among these relationships, cases per million VS risk environment sub-index (*rho = 0.49*) show a slightly moderate positive correlation, especially low positive correlations which the case-fatality rate has with the overall GHS Index (*rho = 0.398*) and health system sub-index (*rho = 0.354*) are significant. These relationships have to

Table 6 Results of correlation analysis

		1	2	3	4	5	6	7	8	9	10	11	12	13
1	Overall GHS Index	1												
2	Prevention sub-index	0.916**	1											
3	Detection and Reporting sub-index	0.844**	0.717**	1										
4	Rapid Response sub-index	0.864**	0.742**	0.649**	1									
5	Health System sub-index	0.922**	0.850**	0.702**	0.778**	1								
6	Compliance with International Norms sub-index	0.703**	0.597**	0.531**	0.570**	0.572**	1							
7	Risk Environment sub-index	0.648**	0.616**	0.337**	0.504**	0.627**	0.314**	1						
8	Days for locks down from the first case	0.564**	0.533**	0.430**	0.537**	0.547**	0.363**	0.344**	1					
9	Tests per M	0.304**	0.298**	0.142	0.216**	0.330**	0.085	0.535**	0.271**	1				

(continued)

Table 6 (continued)

		1	2	3	4	5	6	7	8	9	10	11	12	13
10	Cases per M	0.319^{**}	0.305^{**}	0.143	0.315^{**}	0.364^{**}	0.028	0.490^{**}	0.292^{**}	0.575^{**}	1			
11	Fatality rate	0.398^{**}	0.402^{**}	0.321^{**}	0.299^{**}	0.354^{**}	0.321^{**}	0.290^{**}	0.299^{**}	− 0.005	0.170^{*}	1		
12	Recovery Percentage	0.037	0.023	− 0.049	− 0.001	0.050	− 0.043	0.309^{**}	− 0.033	0.206^{*}	− 0.045	− 0.072	1	
13	Active cases Percentage	-0.172^{*}	− 0.141	− 0.059	− 0.144	-0.163^{*}	− 0.062	-0.384^{**}	− 0.043	-0.210^{*}	− 0.015	− 0.138	-0.903^{**}	1

*Correlation is significant at the 0.05 level (2-tailed)
**Correlation is significant at the 0.01 level (2-tailed)

Table 7 A summary of the results

Country	Days took for domestic travel restrictions	Cases per million	Case fatality rates (%)
United Kingdom	51	3698	14.36
France	52	2170	19.87
Italy	21	3770	14.24

demonstrate negative correlations as countries with high indexes are expected to control a pandemic efficiently. However, the countries such as the United Kingdom, Netherland which are categorized as most prepared by the GHSI have shown case-fatality rates higher than 10%.

(iii) Relationships with testing capacities
'Tests per million' presented a moderate strength of correlation towards risk environment sub-index-$rho = 0.535$. This can be identified as an expected outcome of GHI as the decisions of increasing the number of tests, and supplying adequate infrastructures mostly connects with political decision making, which is evaluated under the category 'overall risk environment'. Further, the indicator 'tests per million' has low positive correlations with the overall GHS Index ($rho = 0.304$) and health system sub-index ($rho = 0.33$). Impact of preparedness in detecting and reporting on the tests conducted by a country is comparatively low ($rho = 0.142$). This is supported by Germany as they have managed to increase their number of tests using the new technique they implemented (pool testing) though they have scored comparatively low in the subcategory of 'detection and reporting' (Bird, 2020).

5 Conclusion

This paper presents two main outcomes; the impact of delay in imposing confinement measures in COVID-19 outbreak; and the importance of preparedness in the overall risk environment of a country including the adequacy of infrastructures. Results revealed that most of the countries which were identified as more prepared by the GHSI have taken more time to make their decisions to go for a lockdown with domestic travel restrictions. These delays in taking aggressive measures have become a possible reason for the higher number of cases and case-fatality rates even though the health systems were comparatively more prepared in countries such as Italy, France, and the United Kingdom as shown in Table 7. This indicates that though the healthcare sector is prepared with sufficient infrastructures and human resources, without timely decision making, its capacities can be exceeded severely.

Furthermore, results reveal an indication that most of the countries who were categorized as most prepared, were overconfident about the capacities of their healthcare systems and other relevant infrastructures. The CDC in the United States guaranteed its citizens a new level of high preparedness for COVID-19 in the early stages with their facilities. Level of public confidence in government decisions and their capacities was comparatively high in these most prepared countries. But in contrast, countries such as South Korea and New Zealand that adopted and imposed strict responsive measures at the early stages have controlled the COVID-19 outbreak comparatively with lower impacts. This suggests that in a pandemic, preparedness of the healthcare system and related facilities cannot withstand alone without effective decision making.

More than the preparedness in detection and reporting, preparedness in the 'overall risk environment' has shown a greater impact on the diagnostic tests conducted in a country. It is reasonable to question why does preparedness in the 'detection and reporting' of countries based on the GHSI results have a lower impact on the adequacy of the diagnostics. One of the possible reasons for this issue could be the criteria used for allocating points in the GHSI since for some questions under sub-indicators, either 1 or 0 points were given. As an example, Germany has obtained only 50 marks for the sub-indicator 'Epidemiology Workforce' while countries such as the US and South Koreas have scored 100. Although there are deviations between the current performances against to control COVID-19 and the expected preparedness level based on the GHSI, still there are possibilities for changes to happen as new COVID-19 cases are still increasing even in June 2020.

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Towards Broadening the Scope of Disaster Risk Reduction: An Exploration of How Epidemic and Pandemic Preparedness is Currently Embedded Within Existing Disaster Risk Reduction Planning in Sri Lanka

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Abstract COVID-19 has illustrated the systemic nature of risk by not only dismantling the health, social and economic aspects of a system but by also giving rise to compound vulnerabilities, particularly in the event of other hazards that occur in parallel with the pandemic situation. Therefore, the United Nations Office for Disaster Risk Reduction [UNDRR] in its Engagement Strategy for COVID-19 Interim Report has stressed on the need for integrating biological hazards into Disaster Risk Reduction [DRR] planning and institutional mechanisms while fostering stronger collaboration between health and DRR authorities. This paper examines the extent to which epidemic and pandemic preparedness has been embedded within existing DRR Planning in Sri Lanka, particularly highlighting the current status and gaps. For the purpose of this study, a thorough review of existing literature on preparedness planning for biological hazards and DRR efforts in the country was carried out referring to policy and legal documents, national and international reports, scholarly articles and internet sources. Further, semi-structured, in-depth interviews were conducted with nineteen purposively selected key informants from the disaster management and health sectors of the country. Results show although 'epidemics' have been included in the interpretation of the term 'disaster' in Sri Lanka Disaster Management Act No.

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13 of 2005, preparedness planning for biological hazards is a predominantly health-sector process the primary responsibility of which is vested with the Director General of Health Services of the Ministry of Health and Indigenous Medical Services. Biological hazards been taken into account in national level DRR policing and planning in the country. Further, even though sub-national level DRR plans have largely overlooked biological hazards, attention has been paid to the epidemic of Dengue in certain districts. Nevertheless, the following gaps remain unaddressed: (1) lack of attention paid to biological hazards in executing DRR programs; (2) lack of technical knowledge regarding biological hazards among disaster management authorities; (3) minimal collaboration between disaster management and health authorities at a planning/decision making level and (4) limited indication of preparedness planning for biological hazards being mainstreamed into sub-national level DRR activities. The study depicts that while there's ample room for integrating preparedness planning for biological hazards into DRR planning in the country, such integration requires a legal framework that advocates a multi-hazard and multi-sectoral approach to DRR.

Keywords Disaster risk reduction · COVID-19 · Biological hazards · Sri Lanka

1 Introduction

Infectious diseases which manifest in the form of epidemics or pandemics have engulfed populations from time to time and have thus been one of the most common causes of mass casualties throughout the world's history (Walsh, 2020). From the plague of Justinian in the 6th Century, the Black Death of the 14th Century to the Spanish flu and the Asian flu in the 20th Century the world has had its fair share of devastation caused by biological hazards (Smith, 2020; Walsh, 2020). Despite the recurring exposure of human populations to epidemics and pandemics, the enormously bleak effects of the recent Corona Virus [also known as the COVID-19 pandemic] raise concerns regarding the preparedness of human systems for biological hazards (Smith, 2020; Walsh, 2020).

At the time of writing, the COVID-19 pandemic has recorded over 42 million confirmed cases and 1 million deaths worldwide (Worldometer, 2020). Apart from the health crisis, the pandemic has dragged the global economy into a deep recession with the World Bank (2020a, b) anticipating a 5.2% contraction in the global Gross Domestic Product [GDP] in 2020. The pandemic has also paved way to a social crisis by disproportionately affecting vulnerable groups [Eg: the poor, the elderly and persons with disabilities] and aggravating inequalities, poverty, discrimination, unemployment and marginalization (United Nations, 2020). COVID-19 has made eminent the systemic nature of risk whereby the health effects of the pandemic have cascaded into adverse socio-economic implications dismantling not only discrete parts of a system but also lending to the failure of the entire system. The potency of the pandemic to cut across and impede the economic, social and environmental pillars of sustainable development has also created the need to rethink the current approaches to mitigating and preparing for other parallel hazards [Eg: climate related hazards] that may occur in the context of the new normal and the resulting compound vulnerabilities (UNDRR, 2020). The UNDRR (2020) in its 'COVID-19 Engagement Strategy Interim Report' has thus, enunciated the importance of a muti-sectoral and multi-hazard approach to managing health related hazards. Thus, in an attempt to provide recommendations towards a more holistic approach to managing biological hazards, this paper explores the extent to which epidemic and pandemic preparedness has been embedded within existing Disaster Risk Reduction Planning in Sri Lanka outlining the current status and gaps.

1.1 Global Agenda for a Holistic Approach to Managing Biological Hazards

Taking into account the systemic nature of pandemic risk and the potential for the creation of compound vulnerabilities through parallel hazards, COVID-19 Engagement Strategy Interim Report has stressed on the need for integrating biological hazards into Disaster Risk Reduction [DRR] planning and institutional mechanisms while fostering stronger collaboration between health and DRR authorities (UNDRR, 2020). This falls in line with the proposal of the Sendai Framework for DRR 2015–2030 to widen the scope of risks to include not only the risks posed by natural or man-made hazards but also those risks from related technological and biological hazards (UNDRR, 2015).

The COVID-19 pandemic and its unfavourable consequences have simultaneously caused the resurgence of the validity and relevance of the Bangkok Principles for the International Conference on the Implementation of the Health Aspects of the Sendai Framework for Disaster Risk Reduction 2015–2030. Following the Ebola Epidemic in West Africa and the Zika virus outbreak in Brazil cum other regions, said conference recommended specific measures for preventing and mitigating the risk of health related emergencies like pandemics and epidemics. Three of seven such recommendations called for:

(1) the promotion of "systematic integration of health into national and sub-national disaster risk reduction policies and plans";
(2) the enhancement of "cooperation between health authorities and other relevant stakeholders to strengthen country capacity for disaster risk management for health, the implementation of the International Health Regulations (2005) and building of resilient health systems" and
(3) fostering advocacy and support for "cross-sectoral, transboundary collaboration including information sharing, and science and technology for all hazards, including biological hazards". (UNDRR, 2020, p. 17).

Accordingly, the management of cumulative risks posed by epidemics and pandemics requires effective cooperation between health and Disaster Management [DM] authorities together with embedding biological hazards in overall DRR policing and planning. Further, while the World Health Organization's [WHO's] Heath Emergency and Disaster Risk Management Framework identifies the Ministry of Health as the leading stakeholder in DRM measures for infectious disease outbreaks, the framework sets out the requirement for the health sector to collaborate with National Disaster Management Authorities heightening focus on prevention and preparedness as opposed to response (WHO, 2019). The framework also exposes the need for fragmented risk management approaches to different hazards to be replaced with a comprehensive risk management approach "that aims to prevent, mitigate, prepare for, respond to, and recover from emergencies". while incorporating specificities relevant for each hazard [e.g. biological, geological, chemical, hydro-meteorological, societal]. A comprehensive risk management approach promises greater efficiency, effectiveness and cost-effectiveness (WHO, 2019, p. 4). Leveraging a comprehensive risk management perspective in managing the risks of epidemics and pandemics evidently requires the incorporation of biological hazards into a country's overall DRR policies and plans accompanied by enhanced collaboration between health and DM authorities. In this paper, the extent to which Sri Lanka's preparedness planning for biological hazards align with the global agenda for a holistic approach to managing epidemics has been evaluated. Such has been evaluated through a thorough exploration of how epidemic and pandemic preparedness is currently embedded within existing national and sub-national level DRR planning and implementation in the country.

1.2 An Overview of the Disaster Risk Management Institutional Framework of Sri Lanka

1.2.1 A Historical Background of the Disaster Risk Management Institutional Framework of Sri Lanka

Sri Lanka became a victim of the 2004 Indian Ocean Tsunami which caused over 35,000 deaths and displaced thousands of people along the coastal belts of the country (United Nations Sri Lanka, 2016). Consequent to the Tsunami and the widespread destruction caused, the need for a systematic approach to disaster management emerged as a result of which a Parliament Select Committee [PSC] on Natural Disasters [2005] was appointed to provide recommendations for such an approach. The recommendations made by this committee were presented in the committee report. Subsequently the central government introduced the Sri Lanka Disaster Management Act as the legal framework for disaster management in the country in May 2005 (Disaster Management Centre, 2014).

The Sri Lanka Disaster Management Act, No. 13 of 2005 addressed aspects such as the formulation of disaster management plans, appointment of technical advisory committees, protocols pertaining to the declaration of a state of disaster and award of compensation, providing for matters connected therewith (Amaratunga et al., 2020).

Said act also included provisions for the establishment of the National Council for Disaster Management [NCDM] as the supreme governing body for Disaster Management in Sri Lanka and the Disaster Management Centre [DMC] as the executing agency of the NCDM (Amaratunga et al., 2020; Ministry of Disaster Management, 2013; Disaster Management Centre, 2020). Later in December 2005, a separate ministry for Disaster Management was formed and in February 2006, the ministry was renamed as the Ministry of Disaster Management and Human Rights with the subject of Human Rights being designated under its purview (Amaratunga et al., 2020; Disaster Management Centre, 2014). The Ministry currently functions as the Ministry of Disaster Management with agencies including the Disaster Management Centre (DMC), Department of Meteorology (DoM), National Building Research Organisation (NBRO) and National Disaster Relief Services Centre (NDRSC) within its purview (Disaster Management Centre, 2014).

As per the provisions of the mentioned Act, the NCDM is chaired by H.E. the president with the Prime Minister Acting as the vice chairman. In addition to chairmanship provided by the President and the Prime Minister, membership of the NCDM constitutes the Leader of Opposition, the Minister in charge of the subject matter of disaster management and Ministers in charge of the following subjects: Agrarian Services; Agriculture; Aviation; Coast Conservation; Defence; Education; Environment; Finance; Forest; Health; Home Affairs; Highways; Housing; Irrigation; Land; Mahaweli Development; Media; Power; Police; Resettlement; Tourism; Urban Development; Water Supply; and Wild Life. In addition to this, the NCDM members constitute Chief Ministers of Provinces and five Members of Parliament representing opposition appointed by the Speaker of Parliament (Ministry of Disaster Management, 2013). The NCDM thus, provides a platform for leveraging ministerial level links for holistic and productive decision making in relation to disaster management in the country (Amaratunga et al., 2020). On the other hand, the Ministry of Disaster Management mainly engages in decision making, policy making and the development of frameworks and guidelines for disaster management in Sri Lanka in consultation with the NCDM. The Ministry is also actively involved in the transmission of decisions taken by the NCDM to Local Authorities (Amaratunga et al., 2020).

The decisions taken by the Ministry of Disaster Management [in consultation with the NCDM] are implemented by the DMC which functions under the purview of the Ministry or Disaster Management. The DMC is the main body for implementing and coordinating Disaster Risk Management activities at both the national and sub-national levels of the country by facilitating the participation of all relevant stakeholders. The main responsibility for activating emergency response mechanisms and tackling pre, during and post disaster situations is vested with the DMC. The DMC consists of six divisions namely: disaster mitigation, research and development division; 24/7 national emergency operation centre and the early warning division; preparedness planning division; training, education and public awareness division; finance division and personal and administration division (Amaratunga et al., 2020; Disaster Management Centre, 2014). In executing its operations, the DMC mainly collaborates with the Department of Meteorology (DoM), National

Building Research Organization (NBRO) and the National Disaster Relief Services Centre (NDRSC) all of which function within the purview of the Ministry of Disaster Management. While the DoM observes and forecasts hydro- meteorological phenomena mainly including floods, landslides, storms, coastal surges and lightening in the country, the NBRO focuses on carrying out research and investigations, risk mapping, monitoring, issuing and dissemination of early warning and mitigation with regard to landslides (Amaratunga et al., 2020).On the contrary, the NDRSC functions as the principle institution for the provision of both short term and long term relief services in the event of a disaster (NDRSC, 2020). The NDRSC maintains a ware house of emergency relief items including Dry Foods, Water, Shelters/Tents, Hygienic Equipments, Health Equipment, Kitchen Utensils, Boat Engines, and Clothes, water pumps, water tanks and water purification equipment. These emergency relief items are distributed in the event of a disaster through the relevant local authorities of the affected community (NDRSC, 2020).

The Sri Lanka Disaster Management Act No. 13 of 2005, also provided the mandate for the development of the National Policy on Disaster Management. This policy contains the "overarching principles and preferred outcomes for disaster management in Sri Lanka" and has been devised based on the provisions of said Act and the Hyogo Framework for Action 2005–2015: Building the Resilience of Nations and Communities to Disasters (Amaratunga et al., 2020, p. 24). Further, Section 8A of the Sri Lanka Disaster Management Act No. 13 of 2005 sets out requirements for the development of the National Disaster Management Plan [NDMP] and the National Emergency Operations Plan [NEOP] under the guidance and assistance of the NCDM and the DMC respectively (Disaster Management Centre, 2014). Accordingly, the National Disaster Management Plan 2013–2017 was drawn and adopted by the DMC in May 2014. The plan illustrates the countrywide Disaster Risk Management [DRM] framework highlight aspects such as disaster mitigation, preparedness, emergency response, post disaster recovery and reconstruction, disaster training and enhancing public awareness (Amaratunga et al., 2020; Disaster Management Centre, 2014). The plan also proposes disaster preparedness and response plans to be drawn at horizontal [Eg: ministerial and institutional plans] and vertical [Eg: provincial, district and divisional level plans] layers (Amaratunga et al., 2020; Disaster Management Centre, 2014). The NEOP, on the other hand, provides specific guidelines on the procedures to be followed, stakeholders involved and the roles and responsibilities of such stakeholders during a state of emergency or a disaster situation (Amaratunga et al., 2020).

1.2.2 An Overview of the Administrative System of Sri Lanka

It is important to note that the existing institutional framework for Disaster Risk Management [DRM] supports a de-concentrated approach to DRM where the primary responsibility of dealing with disasters rests with the national government but is de-centralised to sub national levels, particularly the District Disaster Management Coordinating Units [DDMCUs] (Disaster Management Centre, 2014). Prior to a detailed discussion on the de-concentrated approach to DRM in Sri Lanka, providing a brief description of the administrative system of the country would be useful for the reader. Since the British Colonial period, during which an official system of power came into being, the importance of village level rural administration as a mechanism for effectively reaching the grass root level has been acknowledged. The British system of governance entailed the exercise of colonial powers through the civil service. The civil service was headed by the Governor whose primary task was to formulate executive level policies based on the advice of a council of civil servants. The village headman was assigned with the authority of implementing these policies at the village level. Consequent to independence in 1948, the civil service and the position of the 'village headman' were eventually replaced with Sri Lanka's Administrative Service and the post of 'Grama Niladhari' respectively (Dalpadado et al., u.d.). Currently, Sri Lanka's governance structure consists of three tiers: central, provincial and local. Administration under the central government of Sri Lanka has been diffused to District Secretariats at the district level, Divisional Secretariats at the divisional level and Grama Niladhari offices at the village level. Investigating the manner in which the sub national administrative levels are interlinked, the powers and the functions of the District secretary are implemented at the Divisional Secretariat level while the Grama Niladhari provides assistance at the village/community level to implement the powers and functions of the respective Divisional Secretary. In doing so, the 'Grama Nildhari' administers the respective Grama Niladhari Division which constitutes the smallest administrative unit in Sri Lanka (Kruse, 2007). Currently, there are 25 District Secretariat Divisions [for conducting administrative activities and monitoring and implementing development projects at the district level], 322 Divisional Secretariat Divisions [constituting administrative sub-units under the purview of the Divisional Secretariats] and 14,022 Grama Niladhari Divisions [GN Divisions] in the country (State Ministry of Internal Security, Home Affairs and Disaster Management, 2020).

On the other hand, the authority for provincial level governance is vested with the nine Provincial Councils established for governing the 9 provinces of the country. Further, Local Authorities including Municipal Councils, Urban Councils and Rural Councils represent the local level governing bodies in the country (Amaratunga et al., 2020).

1.2.3 De-Concentrated Approach to DRR: From National to Sub National Levels

As mentioned before, the primary responsibility concerning disaster management in the country is vested with the Central Government represented by the Ministry of Disaster Management which acts under the advice of the NCDM. However, corresponding to the administrative system in the country, this responsibility has been decentralised into sub-national levels including Provincial Councils, District secretariats, Divisional secretariats, Grama Niladhari Divisions and Local Authorities [constituting Municipal Councils, Urban Councils and 'Pradeshiya Sabhas' (or rural councils)] [see Fig. 1] (Amaratunga et al., 2020; Disaster Management Centre, 2014).

The National Policy on Disaster Management, Sri Lanka Disaster Management Act No. 13 of 2005, the National Disaster Management Plan, the National Emergency Operations Plan are the legislative and legally authorised documents that provide formal guidelines on Disaster Risk Management at the national level. Apart from these, the Sri Lanka Comprehensive Disaster Management Program 2014–2018 and the National Disaster Management Plan 2019–2030 stand as relatively recent documents that provide a national level perspective of and guidance for disaster management activities in the country. While the Comprehensive Disaster Management Program 2014–2018 consists of strategies that advocate a multi-hazard and multi-sectorial approach to disaster management in Sri Lanka, the National Disaster Management Plan 2019–2030, at the time of writing, is being developed with emphasis placed on aligning Sri Lanka's disaster management program with the Sendai Framework for Disaster Risk Reduction 2015–2030 (Amaratunga et al., 2020).

As mentioned prior, the DMC acts as the executing agency of the NCDM and implements cum coordinates decisions taken by the Ministry of Disaster Management, thus playing a pivotal role in activating the disaster management program at the national level in the country. The National Disaster Management Plan 2013–2017 sets out the DMC's role in national level Disaster Risk Management as follows: "DMC under the guidance of the NCDM and the M/DM will coordinate and implement the DM programme through a countrywide DRM mechanism, with the main DRM activities being implemented by the respective mandated national agencies" (Disaster Management Centre, 2014, p. 6). To elucidate this statement, while it is clear that the DMC plays a countrywide coordinating role in relation to DRM, the

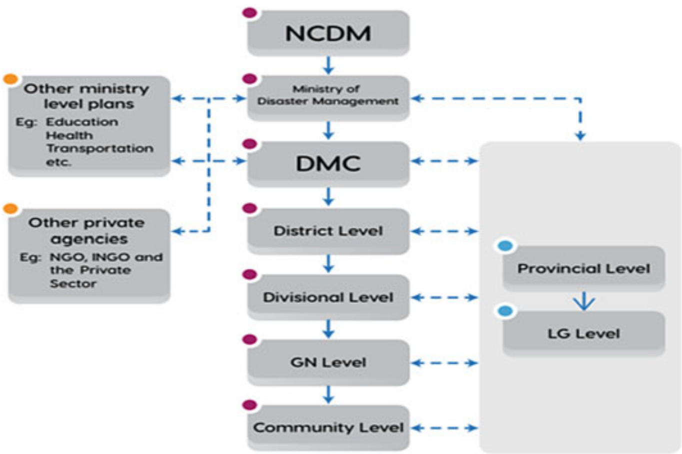

Fig. 1 De-concentrated approach to disaster risk management in Sri Lanka. *Source* Amaratunga et al. (2020)

actual DRM activities pertaining to particular hazards are implemented by the designated technical agencies. Section 10(A) of the Sri Lanka Disaster Management Act No. 13 of 2005 sets out the legal provisions in regard to this as follows:

> 10A. (1) Notwithstanding anything to the contrary contained in any other law, the Minister may, by Order published in the Gazette, designate any one or more of the institutions specified in the First Schedule to this Act (hereinafter referred to as "designated agencies") in consultation with the relevant Ministries for the purpose of assisting the Centre in the discharge of its functions relating to activities connected with disaster management.
>
> (2) The Centre shall issue to a designated agency such directions and guidelines as it may consider appropriate and it shall be the duty of such designated agency to which any directions are issued, to comply with such directions.
>
> (3) A designated agency to which any directions are issued under subsection (2) shall be subject to the supervision and control of the Centre in respect of all matters connected with the carrying out of such directions.

The DRM activities to be coordinated and implemented by the DMC as provided in the Disaster Management Act No. 13 of 2005 and the National Disaster Management plan include Risk Assessment, Data and Information Management, R&D, Use of Space Technology; Mitigation, Climate Change Adaptation, Mainstreaming DRR into Development; Community Based DRM (CBDRM); Preparedness for Response; Early Warning and Dissemination; National Emergency Operations; Needs Assessment, Loss and Damage Assessment, Relief, Immediate Recovery, Rehabilitation and Reconstruction; Training, Education and Public Awareness; Progress Planning, Review, Monitoring and Sub-national Coordination (Disaster Management Centre, 2014). It is thus, evident that the DMC within the purview of the Ministry of Disaster Management has been vested with an overall coordinating role in executing DM measures while the mandated technical agencies are responsible for implementing the DRM program for specific hazards.

1.2.4 Sub-National Level Disaster Management Committees, Their Members and Functions

The rationale behind emulating a de-concentrated [or decentralised] approach to DRR is to ensure the participation of all administrative levels and multiple stakeholders in the Disaster Risk Reduction and Management process (Disaster Management Centre, 2014). With regard to exercising authority over DRM and carrying out DRM related activities at sub national levels, District Disaster Management Coordinating Unites [DDMCUs] were established for each district, immediately after the Tsunami. Each DDMCU consists of a District DM coordinator, Assistant Coordinator and over around 20 DM Assistants who report to the District Secretary at the district level and the DMC at the national level. While the DMC is the overall coordinating authority for DRM in the country, District Disaster Management Coordinating Units [DDMCUs] act as the focal point for coordinating at district, divisional, GN and LA levels (Disaster Management Centre, 2014). Simultaneously, Section 10(F) of the Sri Lanka Disaster Management Act No. 13 of 2005 provides for the establishment of sub-national committees and formulation of sub national plans for disaster management as follows:

> 10F. The Centre shall assist every:
>
> (a) Grama Niladhari division, to prepare a disaster management plan which shall include provisions for the establishment of Grama Niladhari division Disaster Management Committees;
>
> (b) Divisional Secretary, in collaboration with relevant local authorities to collate the relevant Grama Niladhari Division Disaster Management Plans to compile a Divisional Level Disaster Management Plan, which shall include provisions for the establishment of Divisional Disaster Management Committees;
>
> (c) District Secretary, to collate the relevant Divisional Disaster Management Plans to compile a District Level Disaster Management Plan which shall include provisions for the establishment of District Disaster Management Committees; and
>
> (d) Provincial Council, to collect relevant District Level Disaster Management Plans and to compile a Provincial Plan which shall include provisions for the establishment of Provincial Disaster Management Committees.

It is evident in the given section of said Act that legal provisions have been made for the formulation of Disaster Management plans and establishment of Disaster Management committees at the community/village level, divisional level, district level and provincial level. Disaster Management Committees established at aforementioned sub-national levels function as Emergency Management and Response Committees playing a key role during the response stage of the Disaster Risk Management cycle. The members and the functions of these Disaster Management committees have been summarised in Table 1.

1.2.5 Sub-National Level Disaster Management Plans and Their Contents

As mentioned before, Section 10(F) of the Sri Lanka Disaster Management Act No. 13 of 2005 provides for the formulation of sub-national level disaster management plans, specifically, provincial, district, divisional and Grama Niladhari level disaster management plans. This legal provision thereby coincides with both the administrative system and the de-concentrated approach to Disaster Risk Management in the country. Along the same lines, the National Disaster Management Plan points out the requirement for sub-national level Disaster Management plans to conform to the National Disaster Management Plan and the National Emergency Operations Plan (Disaster Management Centre, 2014). Sub-national level disaster management plans include steps to be taken by the respective province, district, Divisional Secretariat Division [DSD] or the Grama Niladhari [GN] Division during different stages of the Disaster Risk Management cycle which entail disaster mitigation, preparedness, response and recovery. For example, the Divisional Disaster Preparedness and

Table 1 Members and functions of sub-national level disaster management committees

Committee	Members	Functions
Provincial disaster management committee	Chaired by a Senior Minister, the Chief Minister, the Governor or the Chief Secretary of the relevant Provincial Council Represented by other officials like Provincial Ministers/Secretaries, the Assistant Chief Secretary and District Secretaries of the Provincial Council. a provincial level representative, his deputy and an additional official for certain organizations	Disaster response activities
District disaster management committee	Headed by the District Secretary Represented by officials including the Additional District Secretary; Divisional Secretaries of the relevant district; district level officers such as the Social Services Officer, Provincial Social Services Officer, Environmental Officer, Samurdhi Officer, Youth Services Officer and other relevant officers attached to the District Secretary's Office; a district level representative, his deputy and an additional official for certain organizations The Assistant Director of the District Disaster Management Coordination Unit acts as the coordinator and the convener	Facilitating the flow of emergency information within the District Secretariat, relevant Divisional Secretariats and other related organizations Coordinating between Divisional Secretariats and other agencies involved in disaster response Mobilizing, deploying and tracking resources relevant for disaster response
Divisional disaster management committee	Chaired by the Divisional Secretary Represented by other officers like the Additional Divisional Secretary; Grama Niladhari Officers of the relevant Divisional Secretariat [DS] Division; Social Services Officer, the Provincial Social Services Officer, the Environmental Officer, the Samurdhi Officer, the Youth Services Officer and other relevant officers attached to the Divisional Secretary's Office; a divisional level representative, his deputy and an additional official for certain organizations The Assistant Divisional Secretary is appointed as the convener and the coordinator	Various functions to be carried out under the following sub-committees: (1) disaster early warning sub-committee, (2) evacuation and sar [search and rescue] sub-committee, (3) relief, temporary camps, food and relief sub-committee, (4) immediate restoration of services, rehabilitation and reconstruction sub-committee and (5) health and welfare sub-committee and other committees as deemed relevant and appropriate

(continued)

Table 1 (continued)

Committee	Members	Functions
GN level disaster management committee	Chaired by the Grama Niladhari officer Religious leaders within the GN Division [Eg: chief priest of the temple, church or mosque], and other village leaders like the Principal of the village school and senior village Ayurvedic doctors are appointed as advisors and counsellors of the committee Members constitute villagers who volunteer to hold membership of the committee	Coordinate with the divisional secretary, GN level disaster management sub-committees and with community groups Identify and coordinate with NGOs to provide emergency relief and carry out other post-disaster activities Organization and coordination of clearance of debris Keep village level information readily available

Source Adapted from Disaster Management Centre, 2006

Response Plan includes baseline data about the DSD, results of a risk and vulnerability assessment of the area, disaster response plans, contact details of focal points, a resources and capacity analysis and standard formats for assessments and reporting (Disaster Management Centre, 2006). Similarly, the GN Level Disaster Preparedness and Response Plan contains a profile of the GN Division, a hazard, vulnerability and risk assessment of the area, disaster mitigation strategies, a response plan, an inventory of resources in the GN Division and the procedure for reporting (Disaster Management Centre, 2006). This study evaluates the extent to which biological hazards have been taken into account in the legislation, policing, planning and execution of DRM activities within the described DRM institutional framework of the country.

2 Methodology

This paper is part of a larger study conducted for examining the current status, gaps and ways of improving the integration of preparedness planning for biological hazards into Disaster Risk Reduction strategies. This paper draws on secondary data gathered through a thorough review of secondary literature including policy and legal documents, national and international reports, scholarly articles and internet sources. Further, primary data was collected through in-depth interviews conducted with nineteen purposively selected key informants representing disaster management and health sectors of Sri Lanka. Key informants from the disaster management sector constituted representatives from the Preparedness Planning Division of the Disaster Management Centre [DMC]; District Disaster Management Coordinating Units DDMCUs] in the districts of Ratnapura, Badulla, Trincomalee and Kilinochchi; United Nations Development Program [UNDP], Asia Pacific Alliance for Disaster Management- Sri Lanka Country; World Vision-Sri Lanka; Ceylon Chamber of

Commerce; District Secretariat of Polonnaruwa; Divisional Secretariat of Polonnaruwa; Medical Officer of Health [MOH] office- Thamankaduwa. Key informants from the health sector involved representatives from the Disaster Preparedness and Response Division [DPRD]; Quarantine Unit; Health Promotion Bureau; College of Community Physicians and the Dengue Prevention Unit. The interviews were conducted using a semi-structured interview schedule that outlined key questionable areas on the representation of biological hazards like epidemics and pandemics in Sri Lanka's DRR planning and implementation efforts as well as the extent of collaboration between disaster management and health authorities. The results of this study have been analysed and discussed under four main themes: (1) Legal framework for the prevention and control of biological hazards in Sri Lanka, (2) Preparedness planning for epidemics and pandemics within national level DRR planning, (3) Preparedness planning for epidemics and pandemics within sub-national level DRR planning and (4) Integration of pandemic and epidemic preparedness into DRR planning at national and sub-national levels: existing gaps and concerns.

3 Results and Discussion

3.1 Legal Framework for the Prevention and Control of Biological Hazards in Sri Lanka

The Quarantine and Prevention of Diseases Ordinance chapter 222, No. 3 of 1897 makes provisions for the prevention of the introduction of the plague and all other contagious and infectious diseases into Sri Lanka and the prevention of the spread of said diseases within and outside of Sri Lanka (Ministry of Health, 2010). In most regulations framed under this Ordinance, the Director-General of Health Services[1] [DGHS] has been assigned as the 'proper authority' for facilitating the prevention of the spread of said diseases (Ministry of Health, 2010). However, the DGHS has delegated some of his powers to the Medical Officer of Health [MOH][2] and the

[1] The DGHS heads the Ministry of Health and Indigenous Medical Services in Sri Lanka with fifteen Deputy Director Generals [DDGs] serving under the DGHS (Epidemiology Unit-Ministry of Health, 2010).

[2] While the DGHS is responsible for the administration of public health services at the national level, this responsibility has been decentralized into sub-national levels corresponding to the administrative structure of the country. At the provincial level, separate ministries of health have been established in each of the nine provincial councils. These ministries are headed by the Provincial Directors of Health Services [PDHS]. Each prov2012ince is sub-divided into administrative districts, the health services of which are administered by Regional Directors of Health Services [RDHS] (Epidemiology Unit- Ministry of Health, 2012). Each district is further sub-divided into smaller regions, the public health services of which are administered by Medical Officers of Health [MOHs]. MOHs are assigned the responsibility of preventive and promotional healthcare in their respective administrative region (Epidemiology Unit- Ministry of Health, 2012). Each MOH area consists of smaller sub-units and each of these sub-units are manned by a Public Health Inspector [PHI] who

Chairman of relevant Local Authority by way of the government Gazette Notification No. 7481 of 28-08-1925 and 10,713 of 17-09-1954 (Ministry of Health, 2010). In accordance with the provisions of said ordinance, the public health authorities in the country including the Disaster Preparedness and Response Division [DPRD] at the Ministry of Health, Nutrition and Indigenous Medicine [which is the central authority for coordinating health-related activities in disaster situations] plays the central role in preventing and/or mitigating the risk of biological hazards, particularly pandemics and epidemics (DPRD, 2018). Evidently, the risks of epidemics and pandemics are required to be managed by a process dominated by the health sector with the central role to be played by the Ministry of Health, Nutrition and Indigenous Medicine (DPRD, 2018).

On the other hand, biological hazards, particularly epidemics, have been taken into account in the interpretation of the term 'disaster' in Section 25 of the Sri Lanka Disaster Management Act No. 13 of 2005, the central Act that governs DRM in the country:

> 'disaster' means a catastrophe, mishap, calamity or grave occurrence affecting any area, arising from natural or human induced causes, or by accident or negligence which results in substantial loss of life or human suffering or damage to, and destruction of property and infrastructure, or damage to, or degradation of, environment, and is of such a nature or magnitude as to be beyond the coping capacity of the community of the affected area and include- a landslide; (b) a cyclone; (c) storm surge; (d) a flood; (e) a drought; (f) an industrial hazard; (g) a tsunami ; (h) an earthquake; (i) an air hazard; a maritime hazard; (k) a fire; (l) an epidemic; (m) an explosion; (n) air raids; (o) civil or internal strife; (p) chemical accident; (q) radiological emergency; (r) oil spills including inland and marine oil spills; (s) nuclear accident; (t) urban and forest fire; (u) coastal erosion and sea level rise; (v) tornados, lightning strikes and severe thunder storms; (w) transport accidents involving hazardous material; (x) any other disaster as may be prescribed by regulation.

As mentioned before, while the DMC is the central authority for executing a country wide DRM program, legal provisions have been made in said DM Act for the DMC to coordinate with designated technical agencies in carrying out disaster related activities. In the context of biological hazards, the Ministry of Health and Indigenous Medical Services, the Epidemiology Unit, Department of Health Services and Medical Research Institute have been assigned as some of the relevant technical agencies that the DMC should coordinate with in carrying out prevention and mitigation activities. Thus, within the current legal framework in the country prevention and control of biological hazards is a dominantly health sector led process where the technical inputs are provided by health authorities and the DM authorities play a coordinating role.

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is responsible for activities such as ensuring sanitation, controlling communicable diseases and improving nutrition and hygiene in the sub-unit. A PHI area is further divided into areas consisting of a population of approximately 3000–4000. This division is done with the purpose of locally carrying out Maternal and Child Health [MCH] activities under the supervision of a Public Health Midwife [PHM] (Epidemiology Unit- Ministry of Health, 2012).

3.2 Preparedness Planning for Epidemics and Pandemics Within National Level DRR Planning

As outlined prior and aligning with the proposal of the Sendai Framework for DRR 2015–2030 to widen the scope of hazards in DRR discourse and practice, the Sri Lanka Disaster Management Act No. 5 of 2013 takes into consideration biological hazards, particularly epidemics in its provisions for DRM in the country. Similarly, while the National Disaster Management Plan identifies hydro-meteorological related hazards as the hazard category that predominantly affects the country, epidemics have been classified a disaster occurring at an 'intermediate level' [see Table 2] (Disaster Management Centre, 2014).

The UNDRR's 'COVID-19 Engagement Strategy' (2020) emphasizes on the need for multi-hazard risk assessments and vulnerability analysis and the importance of taking into account epidemics and pandemics in such assessments. Complying with this, the National Disaster Management Plan demonstrates the importance of taking into consideration man-made and technological hazards including biological hazards [in general] in performing hazard, vulnerability and risk assessments. Said plan recognizes that the risks posed by such hazards are serious and thus, cannot be underestimated. The emphasis placed on performing vulnerability and risk assessments for biological hazards and facilitating preparedness for such hazards have been elucidated in said plan's Annex 1-I as follows:

> Even though epidemics as a direct effect of a disaster are rare, diseases which are common and early spreading could occur as outbreaks, due to secondary or indirect effects of the situation. These diseases may spread as water borne, food borne or droplet infections or as vector borne diseases. Sexually transmitted diseases too can affect the victims in the settlements of the internally displaced population in the long run but not usually as epidemics. However, these epidemics will not cause a disaster situation unless other contributory factors are present. If situations changed, the new diseases such as SARS, Avian Influenza, Hanta virus infection etc. could affect the country as epidemics which might lead to disastrous situations. Thus making plans for the prevention and control of such infections is crucial for the country to be away from "disaster epidemics" and diseases such as dengue" (Disaster Management Centre, 2014, National Disaster Management Plan: Annex 1-I, P. 2).

Further, the 'Strategy of DMC for Disaster Mitigation for Risk Reduction and Mainstreaming in Development' in the National Disaster Management Plan sets out the following activities to be executed in a systematic manner: (1) Preparing Disaster Mitigation Action Plans, (2) Formulating Disaster Mitigation Strategies for Risk

Table 2 Classification of disasters based on the frequency of occurrence

Frequent	Floods, Landslides/slope failures, lightning, tornadoes
Intermediate	Drought, cyclones, storm surges, coastal inundation, epidemics
Rare	Earthquakes, tsunami

Source Adapted from Disaster Management Centre, 2014

Reduction—to be implemented in different ways, (3) Mainstreaming Disaster Risk Reduction into Development Policy, Planning and Implementation, (4) Reducing Vulnerabilities due to Technological Hazards, (5) Reducing Vulnerabilities due to Other Hazards, (6) Consideration of Existing Public Services in Areas of New Development, (7) Risk transferring and financing and (8) Climate Change Adaptation (Disaster Management Centre, 2014). Preparedness planning for biological hazards like epidemics and pandemics has been taken into consideration in this strategy under 'reducing vulnerabilities due to other hazards' (Disaster Management Centre, 2014).

Therefore, is clear that falling in line with the orientations of the Sendai Framework for DRR 2015–2030 and shifts in current DRM approaches commanded by COVID-19, preparedness planning for biological hazards has been acknowledged on legal, policy and planning fronts of national level DRR planning in Sri Lanka.

3.3 Preparedness Planning for Epidemics and Pandemics Within Sub-National Level DRR Planning

In delving into the extent to which biological hazards have been considered in planning and carrying out DRR activities at the sub-national level, it was revealed that while district level disaster management plans have been formulated for all districts of the country, these plans have placed emphasis on preparedness for and response to natural hazards thereby overlooking to a significant degree the prevalence of biological hazards and the need to proactively prepare for and effectively respond to them. However, most key informants interviewed at the sub-national level demonstrated realization of the importance of incorporating preparedness planning for biological hazards into district and other sub-national level disaster management plans with the advent of the COVID-19 pandemic. For instance, when questioned whether a disaster management plan has been formulated for the Ratnapura district, an officer from the District Disaster Management Coordinating Unit, Ratnapura stated,

> "Yes, a Disaster Management Plan has been prepared. Usually, we should update it every five years… Our last plan was formulated in 2018 and we have not considered epidemics and pandemics to a great extent in this plan…. We hope to update the plan in the next year taking into consideration that chain of events that occurred during the COVID-19 pandemic situation" (Key informant interviews, 2020).

Nevertheless, in certain districts, the epidemic of Dengue has been taken into consideration to a certain extent in preparing disaster management plans. Elucidating this an officer from the District Disaster Management Coordinating Unit, Badulla stated,

> We made a disaster management plan earlier. We are in the process of updating it. We are hoping to finish updating it by the end of august. We were supposed to finish it before last year but I had not paid attention to pandemic situations by last year December…In our Act it is said that we have a coordinating role to play during pandemic situations. But, with respect to pandemic and epidemic situations we had paid attention to Dengue. Fortunately,

we couldn't finish this plan last year. So, this year, taking into consideration this experience as well, also because we have provisions in the Act, we are include this into our plan this time.

Similar facts were revealed with respect to the district of Trincomalee as an officer from District Disaster Management Coordinating Unit, Trincomalee claimed,

"The Disaster Management plan for the district has been formulated 6 to 8 years back. Every year we update the plan but this year we are revising the whole plan. Almost done, I think within the month of August we have to print the plan…. upto now we are mainly focusing on natural hazards like floods and all other disasters but biological hazards have not been paid much attention to. But of course we have included some kind of Dengue data but we don't have much input about biological hazards in our plan" (Key informant interviews, 2020).

It was also revealed during the key informant interviews that while sub-national level disaster management committees have not been significantly involved in preparedness planning for and response to biological hazards in general, they have particularly played a crucial role in facilitating preparedness for and response to the epidemic of Dengue in certain districts. As mentioned before, the technical agencies responsible for the mitigation of biological hazards fall under the public health sector of the country. Accordingly, sub-national level disaster management committees have closely collaborated with sub-national level public health authorities like the respective Regional Direct of Health Services [RDHS], Medical Officers of Health [MOHs] and Public Health Inspectors [PHIs]. Illustrating this and commenting on the convening of the District Disaster Management Committee Meetings, an officer from the District Disaster Management Coordinating Unit, Badulla stated,

"If the health sector authorities say that there's a high risk of Dengue…….we would call this meeting. During the Dengue season, the main topic of the meeting would be Dengue. Then the key persons become the health sector authorities. Then we get involved in the plan they prepare and it is that plan that we coordinate….the general Dengue program that is designed by health sector authorities….What we do is that the members of the District Disaster Management Committee are mobilized according to the situation" (Key informant interviews, 2020).

It is evident through the quoted statement that while technical inputs into mitigation, preparedness for and response to Dengue at the sub-national level are provided by health sector authorities, coordination and resource mobilization activities in this regard are carried out by the sub-national level disaster management authorities. Elaborating on this, Dengue cases are monitored at the ground level by ground level health authorities like medical practitioners in hospitals and PHIs. If a significant threat of Dengue is traced, the Regional Director of Health Services [RDHS] of the particular district highlights the issue upon which he/she discusses with the District Secretary and plans to take special actions to address the issue (Key informant interviews, 2020). Consequently, the District Disaster Management Committee meeting is convened and all relevant government officers who attend the meeting are briefed on the situation. Information regarding high risk areas, the actions to be taken, the responsibilities of government authorities, is provided at the District level meeting. During the meeting, it is decided that the Divisional Disaster Management committee should be briefed. Accordingly, the divisional level disaster management committee meeting is scheduled and convened (Key informant interviews, 2020). As mentioned before, Grama Niladhari officers of the respective Divisional Secretariat Division attend this meeting. Based on test reports, the Grama Niladhari officers are informed of high risk Grama Niladhari areas in the Division. Subsequently, the actions necessary to curb the rising Dengue cases like organizing shramadana campaigns, distributing dengue awareness posters, labelling high risk houses and door to door delivery of dengue awareness letters are taken by the respective Grama Niladhari officers take the necessary actions in collaboration with health sector authorities, particularly PHIs. Apart from this, personnel and other resources like the tri-forces, police and financial support from NGOs and INGOs that are required to carry out the aforementioned Dengue prevention activities are mobilized through the District Disaster Management Committee meeting called during a potential outbreak of dengue (Key informant interviews, 2020).

Thus, although biological hazards have been overlooked to a large extent in sub-national level disaster management plans and the activities of sub-national level DM committees, close collaboration between sub-national level DM and health sector authorities in executing preparedness planning activities for Dengue outbreaks can be observed.

3.4 Integration of Pandemic and Epidemic Preparedness into DRR Planning at National and Sub-National Levels: Existing Gaps and Concerns

Although at the national level, DRR planning, policing and legislation in the country have considered biological hazards like epidemics and pandemics, there's not adequate evidence to support that this has been operationalized to a significant degree in the country. Elaborating on this, a key informant from the UNDP claimed,

> "Epidemics is one of the 21 hazards identified in the National Disaster Management Act but in most of our disaster preparedness work which I have engaged in previous occasions we didn't give much attention to epidemics.........I have been engaged in disaster preparedness work in at least 100–150 villages during my career. I can't remember any occasion where we had prioritized an epidemic as a key disaster in these villages. Some of these villages are from the Eastern province, we knew that dengue is a serious case but still dengue didn't come as a serious issue. This is an eye opener for us to revisit our approaches actually" (Key informant interviews, 2020).

In elaborating on why adequate attention has not been paid to epidemics and pandemics in disaster preparedness activities in Sri Lanka, most key informants pointed at the general approach followed in identifying and prioritizing disasters in the country. Disasters that occur in a certain area are identified and prioritized based on people's perceptions and their experiences pertaining to disasters in the relevant area. Further, information available in the 'Disinventar' database, which is the Disaster Information Management System of Sri Lanka, is also utilized in this process. Disasters are prioritized using the Disaster Prioritization Matrix taking into consideration the severity and the frequency of the disaster (Key informant interviews, 2020). Hence, the fact that even persistent epidemics like Dengue have not been adequately prioritized in current disaster preparedness activities in the country calls for the need to reconsider the current approach to identifying and prioritising disasters, and overall disaster preparedness activities for that matter, so that biological hazards like epidemics and pandemics are attributed adequate significance in said activities.

Nevertheless, it was revealed during key informant interviews that recently, especially in the aftermath of the COVID-19 pandemic situation in the country, certain efforts have been made to incorporate epidemic and pandemic preparedness into disaster preparedness activities in the country. For instance, referring to a project executed by the UNDP to strengthen the resilience of Smallholder Farmers in the Malwathu, Mi, and Yan river basins in the northern part of the Dry Zone of Sri Lanka, a key informant from the UNDP said,

> "Now what we are doing is we have a disaster preparedness work, a country plan for floods and droughts basically in the Dry Zone, we are working in three river basins. Now, in addition to those two we have requested our field officers to look at the COVID-19 related similar pandemics and epidemics in their disaster preparedness planning because this is the new normal. We don't know when this situation will fade out from our society. Maybe we'll have to live with this situation for another year or two….so, definitely we have to think about the COVID-19 situation and also this is a good time for us to think about other epidemics also in our disaster preparedness planning because we realise how unprepared we are when we saw this pandemic situation moving through all our villages" (Key informant interviews, 2020).

Evidently, there's close collaboration between DM and health authorities particularly in executing preparedness activities for Dengue outbreaks at the sub-national level with health sector authorities performing a technical role and DM authorities carrying out a coordinating role which involves tasks like resource mobilization and information dissemination. However, it was noted during the key informant interviews that disaster management authorities lack the technical knowledge that is necessary for effective coordination with relevant authorities in the context of preparedness planning for biological hazards. Illustrating this, an officer from the District Disaster Management Coordinating Unit, Trincomalee stated,

> "We are masters in floods and all other natural disasters. Not in the biological hazards…and we can't send our volunteers or our subordinates into the field….the scenario of biological hazards is entirely complex and new to us. So, we have to be empowered on these new biological hazards. Disaster Management Centre has to improve….Health authorities are the expert panel on this thing. So we have to be improved, then only we can effectively coordinate and now we have got some experience but I think we have to learn properly and then only we have to move forward……… Up to now we have very few learned knowledge on biological hazards in Sri Lanka…For floods and landslides we are properly dealing with the respective technical agencies. For floods we are working with the irrigation department. We have a kind of a linear connection and we are almost mainstreamed and we are almost experienced on how we mainstream but this one is kind of new to us" (Key informant interviews, 2020).

The quoted statement indicates that with respect to preparedness planning for natural hazards, the Disaster Management Centre and sub-national level disaster management authorities have adequate technical knowledge to coordinate effectively with the relevant technical agencies. Further, preparedness planning for natural hazards has been mainstreamed into the disaster management activities carried out by sub-national level disaster management authorities. On the contrary, disaster management authorities have limited technical knowledge regarding biological hazards which in turn acts as a barrier to carrying out coordination [including resource mobilization and information dissemination activities] at an optimal level. Apart from this, it is evident that preparedness planning for biological hazards has not been mainstreamed into the disaster management activities carried out by the Disaster Management Centre and sub-national level disaster management authorities.

While it is clear that disaster management and health sector authorities collaborate in preparedness planning for epidemics like Dengue at the sub-national level, a key concern that could be raised at this stage is whether mere collaboration at the field level [where technical aspects are handled by health authorities and coordination activities are carried out by disaster management authorities] is adequate to effectively prepare for and counter biological hazards. This concern mainly arises in the event of parallel disasters where a community is exposed to both natural and biological hazards concurrently. For instance, amidst the COVID-19 pandemic situation, the district of Ratnapura was faced with a high risk of floods and landslides with the onset of the Southwest monsoon (Key informant interviews, 2020). Thus, preparedness planning for the Southwest monsoon had to be configured to suit the COVID-19 pandemic situation that the district was already facing. For example, while in other years families residing in flood prone areas were evacuated to safety houses, steps had to be taken this year to reduce the number of safety houses as far as possible and evacuate vulnerable families to the houses of their relatives/friends. This was done with the objective of containing a potential spread of the pandemic. Elaborating on this, an officer from the District Disaster Management Coordinating Unit, Ratnapura stated,

> "If there's at least one Corona Virus infected person in a camp of 300 or 400 people, we have to quarantine the whole camp. But when we direct a family to a relatives'/friends'/neighbours' house, then we have to only be concerned about the two families in that house. So based on this decision, we directed around 500 people to their relatives'/friends'/neighbours' houses. We maintained only 19 safety houses" (Key informant interviews, 2020).

Further, before people were registered at a safety houses, they were checked for fever by the PHIs and the Public Health Midwives. If a person was diagnosed with fever, they were admitted to a hospital and were thus, not registered at the safety house (Key informant interviews, 2020).

Accordingly, the possibility of being encountered with natural and biological disasters simultaneously emphasizes on the importance of fostering effective collaboration between health sector and disaster management authorities not only at the field level but also in planning and decision making with respect to preparedness for biological hazards. Further, such a scenario of parallel disasters calls for the need to mainstream preparedness planning for biological hazards into the disaster management activities carried out by disaster management authorities in the country, although this may require disaster management authorities to be enlightened on the technicalities pertaining to biological hazards.

Additionally, it was revealed during key informant interviews that in certain districts, separate district, divisional and Grama Niladhari level Dengue committees have been established and functioning under the Ministry of Health and Indigenous Medical Services (Key informant interviews, 2020). Thus, during an outbreak of dengue, in place of activating the sub-national level disaster management committees, sub-national level Dengue committees established specifically to address the issue of Dengue are activated. Having established that biological hazards, particularly epidemics have been taken into consideration in the Sri Lanka Disaster Management Act No. 13 of 2005, it is plausible to state that the formation of separate sub national level dengue committees to carry out dengue mitigation, preparedness and response activities, where sub national level disaster management committees can be utilized for the same purpose is indicative of replication and bureaucratic inefficiency. It is also indicative of the fact that biological hazards like dengue have not been mainstreamed into the disaster preparedness and response activities of certain sub national level disaster management committees through which preparedness planning and response activities pertaining to all other hazard types like natural hazards are coordinated.

4 Conclusion

Preparedness planning for biological hazards in Sri Lanka is a health sector led process that has been allowed for by the country's legal framework for the prevention and control of infectious diseases. The existing legal framework vests the DGHS heading the Ministry of Health and Indigenous Medical Services with the authority to arrive at independent decisions pertaining to the prevention and control of the spread of infectious diseases like epidemics and pandemics in the country. While biological hazards have been considered in DRM planning, policing and legislation at the national level, this has not been adequately operationalized. Evidence also shows that preparedness planning for biological hazards has not been mainstreamed into sub-national level DRR planning and activities. Collaboration between sub-national level DM and health authorities, specifically in preparedness planning for Dengue could be observed, but such collaboration is prominent at a field/operation level rather than at a planning/decision making level.

The findings of this study show that while room for integrating preparedness planning for biological hazards into DRR planning in the country is ample, such integration requires a legal framework that advocates a multi-hazard and multi-sectoral approach to DRM. The existing legal framework for DRM supports a siloed approach where DRM activities address specific hazards with the dominant involvement of the technical agencies designated for each hazard. Thus, effective integration of epidemic and pandemic preparedness into DRR planning in the country calls for the revision and consolidation of legal provisions to promote a multi-hazard and multi-sectoral approach to DRM in the country.

Annexures

Interview Guide

A Representative from the Disaster Management Centre [DMC]

1. Was the DMC involved in planning and/or responding to COVID19? What was that involvement? Was that involvement adequate?
2. To what extent is epidemic and pandemic preparedness currently embedded within existing disaster risk reduction planning?
3. Who is responsible for this aspect of national disaster risk reduction and planning? What actions and measures [in relation to both disaster response and Disaster Mitigation] have been taken in this regard? [Eg: Have response teams been assigned? Have risk and vulnerability assessments been conducted? Have actions been taken to include epidemics and pandemics in future risk profiling activities?]
4. What are the governance structures associated with the epidemic and pandemic preparedness planning including response measures at the national and local levels?
5. The Sri Lanka Disaster Management Act No. 13 of 2005 sets out provisions for the formulation of Provincial, District, Divisional and Grama Niladhari level disaster management plans. Have these sub-national level disaster management plans been formulated? To what extent has any form of pandemic and epidemic preparedness (including Dengue Outbreaks) been included in these plans?
6. The Sri Lanka Disaster Management Act No. 13 of 2005 sets out provisions for the establishment of Provincial, District, Divisional and Grama Niladhari level disaster management committees. Have these sub-national level committees been established? If so, what actions have these committees taken with the guidance of the DMC in relation to pandemic and epidemic preparedness?
7. What national level exercises does the country participate in with regard to epidemics and pandemics? Is there a epidemic and pandemic related drill like in the case of Tsunami? Is the debriefing adequate and lessons learned?
8. The National Disaster Management plan sets out the requirement for Disaster Mitigation Action plans to be developed at sub-national levels [including provincial, district, divisional and Grama Niladhari levels?]. Have these plans been formulated? If so, to what extent has preparedness for biological hazards like epidemics and pandemics been included in these plans?
9. A project proposal for an ‘Integrated Epidemic Risk Assessment’ was put forward in the Ministry of Disaster Management’s publication: ‘Towards a

Safer Sri Lanka: Road Map for Disaster Risk Management'. Has this project been implemented?

10. In the COVID-19 pandemic situation in the country, did the DMC collaborate with the newly established Presidential Task force in providing the grant of Rs. 5000 to economically vulnerable groups?
11. Why wasn't the NDRSC involved in providing relief services during the COVID-19 pandemic situation in the country? Can the current services provided and allocations of the NDRSC be used to address the cascading impacts of epidemics and pandemics? Have actions been taken to formulate an OP for the NDRSC to follow in the event of an epidemic or pandemic?
12. Are there any other authorities assigned to deal with the social and economic impacts (the cascading impacts) of the COVID-19 situation in Sri Lanka. If so, what are they and what actions have been taken or what plans have been formulated in this regard?
13. Are there any other authorities assigned to deal with the social and economic impacts of biological hazards like pandemics and epidemics [including Dengue and Malaria] in Sri Lanka? If so, what are they ad what actions have been taken and what plans have been formulated in this regard?
14. At the national level, what criteria/parameter used in issuing the epidemic and pandemic warning including pandemic response measures?
15. What criteria/parameter is used in deciding the issuance of epidemic and pandemic warning including pandemic response measures?
16. Is there a set of rules/regulations/laws/standard operating procedures (SOPs) guiding the national and local actors in:

    (a) decision for issuing the warning
    (b) disseminating/conveying the warning
    (c) decision for issuing the order for pandemic response measures
    (d) Disseminating/conveying the order for pandemic warning including pandemic response measures
    Please specify these rules/regulations/laws, SOPs.

17. Is the above mentioned set of rules/regulations/laws/SOPs the same across all the national institutions involved in the process? If not, please specify the different rules/regulations/laws that apply to specific institutions.
18. Do current early warning systems address epidemics and pandemics? Who are the authorities and stakeholders involved in issuing and disseminating early warning regarding epidemics and pandemics at the national and sub-national levels?
19. What is the process followed in issuing and disseminating early warning regarding pandemics and epidemics from the national to sub-national levels? What formal and informal communication channels are employed to disseminate warnings and response? How effective are these formal and informal communication channels? How is noise in communication filtered?
20. What are the spatial and socio-cultural aspects involved in the decision making structure within the pandemic early warning system?

(a) National Level
(b) Local Level
(c) Please specify whether they act as strengths, weaknesses or challenges within the interface.

21. What sort of gaps (if any) do you see within the epidemics and pandemics early warning systems?
22. What existing early warning infrastructure could be used to strengthen preparedness planning for epidemics and pandemics?
23. Are the needs to vulnerable groups identified in your preparedness planning? How do you identify vulnerable groups? Have vulnerable populations undergone preparedness training?
24. Is epidemics and pandemics preparedness mainstreamed in the school curriculum? Elementary? Secondary? Higher?

Interview Guide

District Secretaries from Selected Districts

1. Has a disaster management plan been formulated for your district? To what extent has this plan taken epidemic and pandemic preparedness into consideration?
2. Has a disaster management committee been appointed for your district? Who is involved in this committee? What actions have been taken by this committee with regard to any form of pandemic or epidemic preparedness [including Dengue outbreaks]?
3. Have you formulated any disaster mitigation action plans under the guidance of the DMC? If so, to what extent has preparedness for biological hazards like epidemics and pandemics been included in these plans?
4. What role did you play during the COVID-19 pandemic situation in Sri Lanka? Under whose purview did you act in this situation [who gave the orders?]? With what organizations did you collaborate in this situation?
5. Who were the main stakeholders [in the health sector and other sectors] involved in dealing with the COVID-19 pandemic situation in your district? What role did they play and under whose purview did they act?
6. What were the issues/challenges you faced in dealing with the COVID-19 pandemic situation in your district? How did you overcome these issues/challenges?
7. Have risk and vulnerability assessments been conducted for any kind of epidemic or pandemic [including Dengue and Malaria] in your area? If so, with what national level organizations did you collaborate with in this process?
8. Do you maintain a close link with the District General Hospital and other district level health authorities [Eg: Regional Director of Health Services]? What actions have you performed with regard to preventing and planning for epidemics [including and Dengue and Malaria] and pandemics in collaboration with these authorities?

9. Did you collaborate with the District General Hospital and other district level health authorities [Eg: Regional Director of Health Services] during the COVID-19 pandemic situation? If so, what actions did you perform?
10. From whom do you receive early warning messages regarding the onset of an epidemic or pandemic [including Dengue and Malaria outbreaks]?
11. Who is involved in disseminating Early Warning regarding pandemics and epidemics [including Dengue and Malaria outbreaks] at the district level? How do you coordinate and collaborate with these institutions and parties in the Early Warning dissemination process? How do early warning messages in this context flow to divisional and GN levels? What are the formal and informal communication methods/tools used in this process?
12. Who was involved in disseminating early warning and other communications during the COVID-19 pandemic situation in your district? How did you coordinate and collaborate with these institutions and parties in the early warning dissemination process? How did early warning and other communications flow to divisional and GN levels? What were the formal and informal communication methods/tools used in this process?
13. Were you involved in granting Rs. 5000 to economically vulnerable groups during the COVID-19 pandemic situation? If so, what role did you play? With what national level organizations did you collaborate with in this process? With what divisional and GN level organizations did you collaborate in this process? Under whose purview did you act?
14. What role do you play in providing post-disaster relief services? Under whose purview do you act? With what national level organizations do you collaborate in this process? With what divisional and GN organizations do you collaborate with in this process?

Interview Guide

Divisional Secretaries of Selected Divisional Secretariat Divisions

1. Has a disaster management plan been formulated for your Divisional Secretariat Division [DSD]? To what extent has this plan taken epidemic and pandemic preparedness into consideration?
2. Has a disaster management committee been appointed for your [DSD]? Who is involved in this committee? What actions have been taken by this committee with regard to any form of pandemic or epidemic preparedness [including Dengue outbreaks]?
3. Have you formulated any disaster mitigation action plans under the guidance of the DMC? If so, to what extent has preparedness for biological hazards like epidemics and pandemics been included in these plans?
4. What role did you play during the COVID-19 pandemic situation in Sri Lanka? Under whose purview did you act in this situation [who gave the orders?]? With what organizations did you collaborate in this situation?

5. Who were the main stakeholders [in the health sector and other sectors] involved in dealing with the COVID-19 pandemic situation in your DSD? What role did they play and under whose purview did they act?
6. What were the issues/challenges you faced in dealing with the COVID-19 pandemic situation in your DSD? How did you overcome these issues/challenges?
7. Have risk and vulnerability assessments been conducted for any kind of epidemic or pandemic [including Dengue and Malaria] in your area? If so, with what organizations did you collaborate with in this process?
8. Do you maintain a close link with the Divisional General Hospital and other divisional level health authorities [Eg: MOHs]? What actions have you performed with regard to preventing and planning for epidemics [including and Dengue and Malaria] and pandemics in collaboration with these authorities?
9. Did you collaborate with the Divisional General Hospital and other divisional level health authorities [Eg: MOHS] during the COVID-19 pandemic situation? If so, what actions did you perform?
10. From whom do you receive early warning messages regarding the onset of an epidemic or pandemic [including Dengue and Malaria outbreaks]?
11. Who is involved in disseminating Early Warning regarding pandemics and epidemics [including Dengue and Malaria outbreaks] at the DSD level? How do you coordinate and collaborate with these institutions and parties in the Early Warning dissemination process? How do early warning messages in this context flow to GN levels? What are the formal and informal communication methods and tools used in this process?
12. Who was involved in disseminating early warning and other communications during the COVID-19 pandemic situation in your DSD? How did you coordinate and collaborate with these institutions and parties in the early warning dissemination process? How did early warning and other communications flow to GN levels? What were the formal and informal communication methods and tools used in this process?
13. Were you involved in granting Rs. 5000 to economically vulnerable groups during the COVID-19 pandemic situation? If so, what role did you play? With what district level organizations did you collaborate with in this process? With what divisional and GN level organizations did you collaborate in this process? Under whose purview did you act?
14. What role do you play in providing post-disaster relief services? Under whose purview do you act? With what organizations do you collaborate with in this process?

Interview Guide

Grama Niladhari Officers from Selected GN Divisions

1. Has a disaster management plan been formulated for your Grama Niladhari Division [GN Division]? To what extent has this plan taken epidemic and pandemic preparedness into consideration?

2. Has a disaster management committee been appointed for your GN Division? Who is involved in this committee? What actions have been taken by this committee with regard to any form of pandemic or epidemic preparedness [including Dengue outbreaks]?
3. Have you formulated any disaster mitigation action plans under the guidance of the DMC? If so, to what extent has preparedness for biological hazards like epidemics and pandemics [including Dengue and Malaria outbreaks] been included in these plans?
4. What role did you play during the COVID-19 pandemic situation in Sri Lanka? Under whose purview did you act in this situation [who gave the orders?]? With what organizations did you collaborate in this situation?
5. Who were the main stakeholders [in the health sector and other sectors] involved in dealing with the COVID-19 pandemic situation in your GN Division? What role did they play and under whose purview did they act?
6. What were the issues/challenges you faced in dealing with the COVID-19 pandemic situation in your GN Division? How did you overcome these issues/challenges?
7. Have risk and vulnerability assessments been conducted for any kind of epidemic or pandemic [including Dengue and Malaria] in your area? If so, with what organizations did you collaborate with in this process?
8. Do you maintain a close link with the local level health authorities [Eg: PHIS]? What actions have you performed with regard to preventing and planning for epidemics [including and Dengue and Malaria] and pandemics in collaboration with these authorities?
9. Did you collaborate with the local level health authorities [Eg: PHIs] during the COVID-19 pandemic situation? If so, what actions did you perform?
10. From whom do you receive early warning messages regarding the onset of an epidemic or pandemic [including Dengue and Malaria outbreaks]?
11. Who is involved in disseminating Early Warning regarding pandemics and epidemics [including Dengue and Malaria outbreaks] at the GN level? How do you coordinate and collaborate with these institutions and parties in the Early Warning dissemination process? What informal and formal communication tools/methods do you use to disseminate early warning messages to the community?
12. Who was involved in disseminating early warning and other communications during the COVID-19 pandemic situation in your GN division? How did you coordinate and collaborate with these institutions and parties in the early warning dissemination process? What informal and formal communication methods were used to disseminate early warning and other messages to the community?
13. Were you involved in granting Rs. 5000 to economically vulnerable groups during the COVID-19 pandemic situation? If so, what role did you play? With what divisional level organizations did you collaborate with in this process? Under whose purview did you act?

14. What role do you play in providing post-disaster relief services? Under whose purview do you act? With what organizations do you collaborate with in this process?

Interview Guide

Representatives from NGOs, INGOs and International Organizations

1. Have you been involved in responding to the COVID-19 pandemic situation in Sri Lanka? If so, please explain the role you played.
2. With what government sector organizations [both national and sub- national level] did you collaborate in responding to the COVID-19 pandemic situation in Sri Lanka?
3. What challenges/issues did you face in responding to the COVID-19 pandemic situation in the country? How did you overcome these issues/challenges?
4. How were the vulnerable groups identified in targeting your interventions? What criteria did you use to identify these vulnerable groups?
5. How did you adjust your global response measures to COVID-19 to suit the local context of Sri lanka? What were the factors you were most sensitive to in this regard?
6. Have you executed programs or interventions to facilitate preparedness for, prevention and/or mitigation of other biological hazards (Eg: Dengue and Malaria) in Sri lanka? If so, with what government authorities/organizations (both national and sub national level) did you collaborate in executing these programs?

Interview Guide

Assistant Directors—District Disaster Management Coordinating Units of Selected Districts

1. Has a disaster management plan been formulated for your district? To what extent has this plan taken epidemic and pandemic preparedness into consideration?
2. Has a disaster management committee been appointed for your district? Who is involved in this committee? What actions have been taken by this committee with regard to any form of pandemic or epidemic preparedness [including Dengue outbreaks]? How have you coordinated with divisional and GN level Disaster Management Committees in carrying out these activities?
3. Have you formulated any disaster mitigation action plans under the guidance of the DMC? If so, to what extent has preparedness for biological hazards like epidemics and pandemics been included in these plans?
4. What role did you play during the COVID-19 pandemic situation in Sri Lanka? Under whose purview did you act in this situation [who gave the orders?]? With what organizations did you collaborate in this situation?

5. Who were the main stakeholders [in the health sector and other sectors] involved in dealing with the COVID-19 pandemic situation in your district? What role did they play and under whose purview did they act?
6. What were the issues/challenges you faced in dealing with the COVID-19 pandemic situation in your district? How did you overcome these issues/challenges?
7. Have risk and vulnerability assessments been conducted for any kind of epidemic or pandemic [including Dengue and Malaria] in your area? If so, with what national level organizations did you collaborate with in this process?
8. Do you maintain a close link with the District General Hospital and other district level health authorities [Eg: Regional Director of Health Services]? What actions have you performed with regard to preventing and planning for epidemics [including and Dengue and Malaria] and pandemics in collaboration with these authorities?
9. Did you collaborate with the District General Hospital and other district level health authorities [Eg: Regional Director of Health Services] during the COVID-19 pandemic situation? If so, what actions did you perform?
10. From whom do you receive early warning messages regarding the onset of an epidemic or pandemic [including Dengue and Malaria outbreaks]?
11. Who is involved in disseminating Early Warning regarding pandemics and epidemics [including Dengue and Malaria outbreaks] at the district level? How do you coordinate and collaborate with these institutions and parties in the Early Warning dissemination process? How do early warning messages in this context flow to divisional and GN levels? What are the formal and informal communication methods/tools used in this process?
12. Who was involved in disseminating early warning and other communications during the COVID-19 pandemic situation in your district? How did you coordinate and collaborate with these institutions and parties in the early warning dissemination process? How did early warning and other communications flow to divisional and GN levels? What were the formal and informal communication methods/tools used in this process?
13. How prepared are you to face a landslide that occurs during the COVID-19 pandemic situation in the country? What actions have you taken in this regard?
14. Have you taken into consideration the COVID-19 pandemic situation and its effects in your preparations for the South West monsoon?

Interview Guide

Representatives from the Disaster Preparedness and Response Division [DPRD]; Quarantine Unit; Health Promotion Bureau; College of Community Physicians and the Dengue Prevention Unit

1. Is epidemic/pandemic preparedness currently embedded within existing disaster risk reduction planning?
2. What is the role of your organization towards epidemic and pandemic preparedness planning in Sri Lanka?

3. What are the legal provisions which define your role in epidemic and pandemic preparedness planning?
4. In what level of administration (National, provincial, local), your organization involved in epidemic and pandemic preparedness planning?
5. Who are the stakeholders in epidemic/pandemic preparedness connects with your organization (National governing bodies, Ministries engaged in the process, Disaster Management Center, Public Health Authorities, Tri-forces, NGO/INGOs)?
6. How does your organization connect with the other stakeholders of epidemic and pandemic preparedness planning?
7. How the potential cascading impacts are addressed in your process of epidemic and pandemic preparedness planning?
8. Are there already developed SOPs/ guidelines/ circulars etc. to be followed by your organization? If yes what are they? If no, what are the underlying reasons?
9. Are the above mentioned SOPs/ guidelines/ circulars etc. in effect same across all the administration levels?
10. What is the level of involvement of the Public Health Authorities in the process of epidemic/pandemic preparedness?
11. What are the public health authorities involved in epidemic/pandemic preparedness planning?
12. How effective is the coordination between the Public Health Authorities?
13. Are the needs of vulnerable groups identified in your preparedness planning? How do you identify vulnerable groups? Have vulnerable populations undergone preparedness training?
14. How is your preparedness towards the sudden outbreaks of diseases with unknown sources?
15. Have you/your organization been involved in planning and/or developing strategies to respond in COVID19? What was that involvement? Was that involvement adequate?
16. Is the role of your organization in epidemic and pandemic response, predefined? If yes where it is defined and what is the role?
17. Who are the stakeholders coordinating with your organization in the phase of epidemic/pandemic response?
18. How do you coordinate with the other stakeholders in the phase of the epidemic/pandemic response?
19. Does your organization have the authority to generate early warning messages? If no, who is the responsible authority?
20. Does your organization have the authority to disseminate early warning messages? If no, who is the responsible authority?
21. How does your organization connect with the existing national early warning system?
22. What sorts of gaps (if any) do you see within the epidemics and pandemics early warning systems?

23. How the existing early warning systems for epidemic and pandemic can be strengthened?
24. What are the other information have to add more than what you have mentioned earlier?

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