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Chandan Ghosh
Sreevalsa Kolathayar *Editors*

A System Engineering Approach to Disaster Resilience

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Preface

Technological advancement and innovation have created new opportunities for enhancing disaster resiliency and risk reduction. The 2030 Agenda for Sustainable Development has helped raise awareness of the importance of disaster and emergency management: of the 17 Sustainable Development Goals established by the United Nations, four of them (Goals 1, 2, 11 and 13) refer to the need of all nations and communities to address the challenges related to natural hazards and disasters. System engineering perceptions are relative in time and space and thus swing the balance between analytical edifice and transboundary constraints and more often when they are translated into disaster resilience, public policy and action at the ground. This book presents the select proceedings of the Virtual Conference on Disaster Risk Reduction (VCDRR 2021). It emphasizes on the role of civil engineering for a disaster resilient society with particular reference to how the mitigation of and the adaptation to the risks of natural disasters that can be strengthened through the application of systems engineering perspectives. Such work has only recently just begun, and there are great opportunities to apply techniques of simulation modelling not only for academic interest, but also being applied to reduce the exposures of lives and property due to increasing disaster events across the globe. The government sector at local, regional, and national levels as well as the private sector, notably insurance companies, academia, researchers, shall be immensely benefited in utilizing various system engineering tools elaborated in the book. Various topics covered are climate change adaptation, psychosocial issues, community resilience, post-disaster reconstruction, slope mitigation, strengthening measures, health monitoring of infrastructures, dam safety, etc. This book is a comprehensive volume on disaster risk reduction (DRR) and its management for a sustainable built environment.

New Delhi, India — Prof. Chandan Ghosh
Surathkal, India — Dr. Sreevalsa Kolathayar

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About the Editors

Prof. Chandan Ghosh has devoted more than 30 years of his career in UG & PG teaching, research guidance, development of teaching tools & training modules for engineers, architects, and town planners. He has earned professional zeal in promoting Disaster Mitigation Technologies, including seismic base isolation, dampers, lightweight materials, etc. Besides developing some of the IEC materials such as "Snake and ladder game" for earthquake, flood, road safety, cyclone, DM plan for family, Prof. Ghosh has been deeply involved in conducting workshops/seminars on retrofitting, earthquake-induced damages, and landslides mitigation; taking pilot site-specific technical/experimental studies; developing/moderating of training modules; online training programs and curriculum for the self-study certificate program. He is always available for the community services and awareness campaign through experimental as well as field demonstration, social media, and video documentaries. Professor Ghosh is a prolific motivator in varied sustainable development activities, including bio-engineering measures for landslides/erosion controls, lake water cleaning by natural means, and urban flood mitigations. As a recognition of his seminal contributions, Prof. Ghosh received Prof. Leonard prize for the best doctoral thesis-1993, CIDC-Vishwakarma Awards-2013, IGS-Shri H. C. Verma Golden Jubilee Award-2013, and Lifetime achievement Award-2019 by IGS-Delhi Chapter.

Dr. Sreevalsa Kolathayar pursued his M.Tech. from Indian Institute of Technology (IIT) Kanpur, Ph.D. from Indian Institute of Science (IISc) and served as International Research Staff at UPC BarcelonaTech Spain. He is presently Assistant Professor in the Department of Civil Engineering, National Institute of Technology (NIT), Karnataka. Dr. Kolathayar has authored six books and over 80 research articles. He is Associate Editor of two International Journals. His broad research areas are geotechnical earthquake engineering, geosynthetics and geonaturals, landslide, disaster risk reduction and water geotechnics. He is currently the Secretary of the Indian chapter of International Association for Coastal Reservoir Research (IACRR), and Executive Committee Member of Indian Society of Earthquake Technology. In 2017, The New Indian Express honored Dr. Kolathayar with 40 under 40—South

India's Most Inspiring Young Teachers Award. He is the recipient of ISET DK Paul Research Award from Indian Society of Earthquake Technology, IIT Roorkee. He received "IEI Young Engineers Award" by The Institution of Engineers (India), in recognition of his contributions in the field of Civil Engineering. He was recently featured in Geostrata Magazine by American Society of Civil Engineers (ASCE). Dr. Sreevalsa is the Organizing Chair of the Virtual Conference on Disaster Risk Reduction (VCDRR 2021).

A System Engineering Approach to Disaster Resilience—An Introduction

Chandan Ghosh and Sreevalsa Kolathayar

Abstract In this dynamic earth, each and every place is affected from natural, technological, biological, environmental hazards and/or related impacts. Depending on the extent of resilience measures in place and socioeconomic status of the countries, their infrastructures and environmental sensitiveness, the damage, and loss patterns are exposed. So to ensure basic security and quality of life against all, impending hazards have been the key issues for the academia and industries vis-a-vis administrative setup. Therefore, disaster resilience has become a systemic challenge for the mankind, and eventually, responding to disasters has been into the mainframe of all concerned governance from the time that natural resources are being extracted and used for the exploiting more and more from the mother nature. But in recent times as we are making lots of infrastructural growth, it is more so critical with the onset of deadly infectious disease outbreaks, acts of terrorism, social unrest, and fluctuation in the share market leading to financial disasters. From perspective of system engineering approaches, this chapter explains various facets of disaster resilience paradigm with particular motivation to the infrastructure growth and sustenance. Additionally, a summary of the 38 selected papers categorized into six sub-themes about the necessary approaches to elevate resilience to disasters is presented.

Keywords Disaster management · Resilient infrastructure · Disaster risk reduction · Sustainable development goal · Sendai framework · System engineering

1 Introduction

The recurrence interval, ferocity, social, and economic impacts of disasters show exponential trends in recent decades. Cities and countries around the world have been facing hydro-meteorological events such as cloud burst, cyclone, storms, droughts

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resulting humongous impact to the economy, and life loss. More than a billion population of the world live within 10 m from the coastline and with projected sea level rise of 1 m by the year 2100 [1, 2], several of these sea protection dykes will become either ineffective or to raising them cost will be substantial. However, for developed countries, like Netherlands, UK, and Germany, dykes so built up have the higher protected value, yet raising of these dykes to cater sea level rise would be of monumental task. In fact, the reliable and resilient protection of low-lying regions and coastal cities from flooding, land loss, water-logging, and groundwater salinity is a both costly and technologically complex process. From this one aspect of potential disaster threat domain, amid accelerated urbanization throughout this century, more and more economic activity are going to be concentrated in risk-sensitive areas; especially as new cities throughout South Asia and Africa are likely to be concentrated in the highest risk areas [3, 4], which is as much as they are now being faced in the North America and Europe. Disaster management, in general, aims to mitigate the potential damage from the hazardous event and ensure real-time immediate rescue and assistance to the victims, and attain effective and rapid recovery in the motto of "building back better." The mitigation of and the adaptation to the risks due to natural and/or man-made events can be accomplished through the application of systems engineering perspectives consisting of Internet of Things, Drones integrated with GIS for mapping of facilities, analytical and numerical modeling techniques, AI-ML, data science tools, and information, education and communications technology (IECT). Such integration work has recently attracted multidisciplinary teams, and more so there are ample avenues to explore real-time broad-based simulation modeling not only for accelerating academic zeal, but also devise measures to reduce the exposures of lives and property damages. As many disasters including COVID-19 are of trans-boundary nature, the national and government sector at local, regional levels, as well as the private/public sectors, and re-insurance companies, have strong emphasis in harnessing various system engineering approaches. Some of the long-range IoT based wireless technologies including customized UAVs provide real-time panic alerts, tracking trapped/victims, and communication during disaster situations. They are also able to account for the safety of human and animals, real-time remote measurement of air-quality like temperature, humidity, pressure, CO_2, and light-intensity and contact tracing of the disease causing pathogens in the vicinity. This chapter considers how a systemic approach can improve resilience measures against portending risks and thereby to explore recovery process [4, 5]. Based on the contributions from the experts, six sub-themes are made: disaster preparedness; climate change adaptation and mapping tools; resilient city and flooding; community resilience measures; dams and slope mitigation; and strengthening and retrofitting measures. In the subsequent section, some aspects of system engineering measures toward resiliency including some of the current international framework in disaster risk reduction (DRR) will be discussed followed by salient points made in each of the paper.

2 Disaster Preparedness

Giving an account of our foreseeable existence in this earth, how well we are fit to live with sustainable future and what are the footprints in terms of infrastructure such as dams, roads, transportation facilities, telecommunication, industries, education, exports and imports of goods, and other various developments, K. Sukumaran gives a full treatise in his paper titled *Impact of Human Activities Inducing and Triggering of Natural Disasters.* It is also mentioned that with annual increase of 74 million peoples per year, the global population will become 8 billion by 2024 and thereby needing huge quantity of natural resources in various forms that cause depletion of natural resources, resulting in environmental degradation, generation of wastes, greenhouse gases predominantly CO_2, pollution of air, water, land, deforestation, urban heat islands, traffic congestions, etc., which are causing disasters and calamities. The paper also cited various reports defining ecological footprints, and as per 2019 data that global average economic loss due to all types of natural disasters amounted to $232 billion. The world population is unevenly distributed as developed countries have less population (1 billion) than in developing countries (6.8 billion). The author explained several aspects of environmental degradation, exploitation of huge quantum of all forms of natural resources for human needs and in turn producing waste, pollution, depletion of natural resources, loss of bio-diversity, emission of greenhouse gases that inflict to the global warming and climate change. The repercussion of earthquakes, hurricanes, tsunamis, floods, droughts, melting of glaciers, rise in sea level, wildfires, landslides, heat and cold waves, etc., causes loss of human lives, destruction and damages to infrastructure, epidemic and pandemic, etc.

Nosini et al. explained in *Implementation of Build Back Better Concept for Post-Disaster Reconstruction in Sri Lanka* that post-disaster reconstruction (PDR) can be considered as an opportunity to undertake improvements in lifestyle, safety, and economy of disaster-affected community. Citing successful adoption of the Build Back Better (BBB) approach after Indian Ocean Tsunami (2004), this study determines the practices of in PDR projects to accomplish disaster risk reduction and community recovery through effective and efficient implementation of PDR in three landslides affected areas in Sri Lanka. Further, they suggest the necessity of identifying strategies to overcome the challenges of BBB implementation in order to succeed in future PDR projects worldwide.

In a paper titled *Disaster Affected People's Vulnerability Assessment Through Addressing Padma River Bank Erosion,* Awual Baksh et al. identified the extent of damages of the resources, economic crisis, unemployment problem, food crisis, various diseases, social problems. household income, availability or cost of building materials, legal and social limitations on land use, etc. The researchers suggest specific actions, such as construction of protection dykes and maintaining the health of same by community to prevent the rapid river erosion along the Padma river banks in Bangladesh.

Dev and Dash (*An investigative study on material and its performance of intermediate disaster relief shelters*) explore the types of intermediate relief shelters with respect to various materials available and case studies addressing the key factors related to the environmental, economic, technical, and sociocultural criteria affecting the provision and performance of relief shelters. They proposed key aspects to be taken into consideration during the decision-making and design processes of such shelters for the effective and better performance for the community. The authors made critical remarks on the regional cultural disparities, livelihoods, lifestyle, sociopolitical setup, available resources, materials, technology, modality of financial resources, and context-specific constraints and opportunities that foster local capacity for reconstruction. The authors tried to identify the most reliable method which would be productive, fastest, and satisfactory when empowered by affected people themselves. It is further noted from the paper that every organization's external participation could best be directed at improving peoples' efforts to build their intermediate shelters by promoting gaps in the material, finance, expertise, technical guidance, and needed craft tools.

Emphasizing on the development of an emergency food aid plan (EFAP), Satesh Balachanthar and Lee Lai Kuan (*Development of Emergency Food Aid Plan for Renal Disease Patients: A Vital Disaster Preparedness*) presented a predictive tool to inform both individual, household, and evacuation centers of the appropriate dietary recommendations during disaster for chronic kidney disease victims. Selection of food was based on the following three scenarios: Ready-To-Eat (RTE), Emergency Food Basket (EFB), and Emergency Congregate Feeding (ECF) at the evacuation centers. The authors explained about cost-effective food aid by employing linear programming and scenario development, and this study established the designation of a nutritionally appropriate, cost-effective, socially acceptable, and sustainable emergency food aid plan for disaster preparedness and abatement.

Using psychological mindset and socioeconomic conditions over the levels of disaster preparedness, Kolathayar et al. (*Understanding Disaster Preparedness Level in The South Indian City of Chennai)* developed a Disaster Preparedness Index (DPI). The authors developed a questionnaire based on the parameters such as past disaster experience, perception toward disaster risk, personal and community participation; roles of individuals, community and government in disaster management, preparation measures, and demographic details. Taking case study of Chennai city, India, the study showed that the society is mostly poorly prepared, and there is a need to increase the social awareness and preparedness measures to build a secure disaster resilient society.

S. Divya Sankar et al. *(Emergency Preparedness and Response—an Evidence Based Onsite Audit Conducted in Two Hundred Organizations)* explained occupational health and safety management system (*BS 18001, ISO 45001*), which is an integral part of most of the organizations across the world along with other management systems like quality, environment, and energy. The authors emphasized that the emergency preparedness and response procedure is not a onetime documented information, but it is a proactive and ongoing process which has direct correlation with the hazard identification and risk assessment. Further, the industry-specific research study could be conducted to determine the adequacy and suitability of the emergency preparedness and response. At the end of the paper, the author provided a questionnaire on “Emergency Preparedness and Response.”

Amarjeet Kumar et al. (*Framework for location-allocation of shelters for evacuation during cyclones*) discussed about the framework by using location-allocation model with constraints such as supply at shelters, travel cost between origin and destinations, and risk clustering for the case of cyclones frequently happening in the East coast of India. Their studies are aimed for the emergency planners in devising appropriate strategies to minimize the cost of operation by allocating resources efficiently for a successful evacuation. This study attempted to identify evacuee-allocation methodology and the impact of staged evacuation on shelter allocation (in both permanent and temporary shelters) and on the travel distances arising from such shelter choices. Presenting an elaborate case study for a district in the coastal belt of West Bengal, India, the authors recommend to study many hazard scenarios to identify long-term and short-term strategies for planning locations of permanent shelters, relief supplies, hospitals, and resource personnel’s for effective disaster response.

3 Climate Change Adaptation and Mapping Tools

Citing 2020 unseasonal flood in the capital city of India’s Telengana district, Abdul J Sharief and B Vangipuram (*Assessment of Socio-Economic Impact of Urban Flooding In Hyderabad Due To Climate Change*) presented various factors for alarming rates of urban disasters. Representative concentration path (RCP) method for future rainfall data is presented till the year 2100 using socioeconomic factors such as the per capita income of people, the extent of disruption of economic activity, supply chain disruption, and the possibility of people pushed into poverty again. The authors emphasized that their model will help future policy making and mitigation efforts for the reduction of damages caused by urban flooding. The study could foresee the poor and low-income group section being affected more by the flooding than other income range of the corresponding flood-surveyed areas. The study also mentioned that the economic losses due to urban flooding in India account for the range of 1.1$ billion to 5$ billion a year, and these losses do not account for the impact of these floods on informal settlements like slums that reside usually in flood-prone areas and small businesses in these localities which are subjected to the vulnerability of shutting down their respective business.

Kiran et al. (*Application of ArcGIS and HEC-RAS in Assessing Sedimentation in Godavari River Reach*) used the weighted coefficient of determination ($\omega r2$), Nash–Sutcliffe efficiency (E), modified Nash–Sutcliffe efficiency ($E1$), and modified index of agreement ($d1$) to provide an objective assessment about the closeness between the simulated and observed values. However, compared to HEC-RAS for the Godavari river between Perur and Polavaram stations, India, the Wilcock-Crowe model provides more accurate estimates of sediment discharge and deposition and erosion at each cross section along river reach.

Giving the list of blast events happened between 1998 and 2004 in almost all the states and Union Territories of India, C Murali Krishna and Tezeswi P Tadepalli (*Decision Support Tool for Blast Mitigation)* developed a standalone and straightforward MATLAB based GUI-GIS tool for blast damage prediction as well as blast mitigation efforts such as access control, standoff, and hardening of critical infrastructure. Only explosions caused by high explosives (chemical reactions) are considered within the study, and building damage level and number of causalities were not considered in the tool.

In the paper *(Pavement Design Considering Changing Climate Temperature) by* Swapan Kumar Bagui et al., the use of performance grade (PG) or polymer modified bitumen (PMB) with higher softening point to cater for the thermal changes are explained. They have highlighted the impact of environmental conditions change, faster pavement deterioration; thus incurring additional costs to the road construction authorities. Life Cycle Cost (LCC) and initial construction cost of pavement are also calculated and presented in the paper for conventional pavement and permanent pavement.

Nur Mohammad Ha-Mim and Zakir Hossain (*Application of GIS and AHP Based Integrated Methodology for Mapping and Characterization of Associated Socioeconomic Vulnerability to Natural Hazards at Union level: A Case Study of Southwestern Coastal Bangladesh*) elaborated on reason for vulnerability in Bangladesh such as the flat topography, heavy monsoon rainfall, discharge of sediments, drainage congestion, active fault line, low river gradients, and shallow funnel-shaped Bay of Bengal. They have selected 20 indicators to construct the socioeconomic vulnerability index under three major components: physical and infrastructural, socio-demographic, and economic components. Based on the three districts chosen for this study, the results demonstrate the extent of socioeconomic vulnerability as very high (17.8%), high (46.6%), moderate (21.7%), low (11.5%), and very low (2.4%). The paper emphasizes for policymakers to make decisions regarding development strategies and to plan for disaster risk reduction by exploring the level and extent of vulnerability at the local level. Overall, the authors state that land use planning is the key for resilience and sustainable urban development.

Citing climate change resilience through land use in urban regions due to density, population, and extent of economic prosperity, Meghna Anilkumar and Shyni Anikumar's study *(Resilient sustainable land use planning for climate change adaptation for an urban area)* identifies a pathway for its adoption into mainstream decision making. For this management, quantification and threshold analysis are required through carrying capacity analysis and ecological management plan. This paper also shows how to bridge the gap between planning and disaster management through adaptation and also between climate change studies and land use planning.

4 Resilient City and Flooding

Sánchez Y. et al. in their paper on *Identification of Risks in the Water Conduction Infrastructure for Supply Systems, a Strategy to Increase Resilience* proposed to identify and assess risks in the main water conduction systems in Cuba. They have identified various aspects of vulnerability such as inadequacy of infrastructure, lack of monitoring, inadequate management policies and many others aspects described in the paper. The authors presented the methodology to be followed for the identification and evaluation of risks in water supply conduction systems, resulting in the adaptation to the Cuba's context, and also linking to the international methodologies available.

KY Lim and KY Foo (*A State-of-The-Art Review on the Unique Characteristics, Key Driving Causes and Mitigation Measures of The World Catastrophic Flood Disasters*) explained about diverse characteristics, frequency, magnitude, causes, and impacts of the sudden flooding, which are largely affected by the unique physical geographical elements, population distribution patterns, socioeconomic status, land uses, river training, and hydro-meteorological dynamics. This paper postulates the initial platform to provide a concise and comprehensive information on the evolution of historical flood events recorded in each continent of the world since nineteenth century. The authors presented a complementary set of structural and nonstructural measures, which have brought both beneficial and detrimental changes in the hydrography and ecology of riverine environments.

Based on Ministry of Road Transport and Highway data, India, Priyank Trivedi and Jiten Shah considered human factors, vehicular factors, road and environmental factors (*Road Accident Hazard Prevention by Applying the Haddon Matrix)* in their paper. The Haddon Matrix highlighted the major influencing determinants for the state of Gujarat, India, and the analysis provides the most affecting factors at pre-crash, during the crash, and post-crash scenario with suitable preventive strategies at every stage. It is noted that road accident-related disaster is very much alarming with 90% of road accident deaths share by only lower- to middle-income countries of the world. The authors noted that Indian road accident death rates and the hazardous scenario if goes unchecked right now, the number of death may cross the mark of 250,000 by 2025. The authors' finding supports the importance of road safety awareness education among citizens and intrinsically, existing road safety practices according to crash phases have to be reconsidered for further improvement with interdisciplinary crash hazard reduction strategies.

R. Jeya Prakash et al. *(No Fine Concrete Pavement—A Sustainable Solution for Flood Disaster Mitigation)* presented the results of elaborate experimental investigations on the mechanical properties of no fine concrete pavement (NFCP) by including compressive strength, split tensile strength, and the hydraulic conductivity of fiber reinforced no fine concrete (FRNFC). The porosity in pavement can be ensured through the removal of fine aggregates in mixture design and maintaining the acceptable void content, so that excess runoff water does freely infiltrate being a self-resilient infrastructure. The results clearly indicate that both the compressive strength and permeability of FRNFC linearly depend on the dry unit weight of the samples and values obtained are found within acceptable limit specified for NFC.

Highlighting about recent recurrent flood disasters amid the rapid urbanization in Kerala, Amrita Vinod and Manoj Kumar Kini (*Disaster-resilience and Rehabilitation in Kerala: A Critical Review of CARe-Kerala's Housing Scheme*) described how the state government adopted housing solutions for the affected population. The authors presented an assessment report with a critical examination of the prominent features of CARe-Kerala housing projects. The projects emphasized resilient modules utilizing alternative methods and construction techniques. The paper mentioned how the climate change impacts compounded by the state's absence of the adaptive ability to floods, droughts, and mudflows that led to the increase in the disaster frequency and severity. The second author of this paper is involved in the entire project CARe, in which, technical support and advisory provided appropriate interventions on the diverse terrains of construction to ensure maximum efficacy and safety with optimum resource consumption.

5 Community Resilience Measures

Bindu. C. A. and Subha Vishnudas (*Measuring Disaster Resilience at Community Level And Exploring the Prospects of Revitalizing Communities Coalescing Disaster Risk*) emphasized on the efficiency of disaster response, discouraging development in vulnerable areas and increasing the resiliency of community toward disasters in dealing with disaster risk reduction and mitigation. The authors corroborated by establishing that coalescing disaster risk into development activities contributes to long-term endurance, resurgence, resilience, and revitalization of the community.

Addressing the various natural hazards and their impacts on to the society, it is very much imminent to anticipate about the communication for evacuating, safeguarding, and preventing humans as soon as possible. S. Arvindan and D. S. Vijayan (*Safeguard and Preventive Measures of Natural Disasters Using Early Warning Systems—A Comprehensive Review*) present the role of early warning systems in major natural disasters such as earthquakes, tsunamis, landslides, volcanos, wildfires, and epidemics. The authors reviewed current literatures on providing and improving monitoring equipment, building capacity, and training in the way weather stations are maintained and data collected, etc. Notable among them are about the development of integrated biosensor system with mobile health and wasted water-based epidemiology to monitor the feasibility of the widespread COVID-19 worldwide. This system also helps preventing the rapid intervention and diagnosis, and it responds to the information everywhere quickly and thus minimize the pandemic's spread. The paper discusses about the current state of the art in the EWS related to earthquake, volcano, Tsunami, flood, and landslides.

Sharmin Akter et al. *(Potentiality Assessment of Community Open Space for Disaster Management Purpose: A Participatory Approach to Reduce Disaster Vulnerability on a Community)* defined the concept of the community participated disaster vulnerability reduction to identify associated risk, capacity, and potentiality of using open spaces for disaster management purposes. Based on the study, the authors proposed community developed strategies and different types of proposals from community peoples and experts to identify the ultimate potentiality. To assess the existing vulnerability associated with the study location, four different participatory tools, such as historical trend of open space and water body reduction, existing social and physical vulnerability of the area, cause-effect diagram, and pairwise ranking matrix, were used. The method, so developed, can be applied to identify all of the aspects of disaster management for other communities as well. The authors corroborate that while the traditional disaster management approach requires much time and has a high potentiality of failure of the plan, the community-based approach helps to find the root cause of the problems and also helps to find out the most reliable solution to the problems. Accordingly, the participatory approach helps to empower the community and helps to make them believe that they are also a part of the comprehensive planning procedure. This process, as explained, helps to create self-respect, ownership, accountability, and awareness among the community people.

Naga Venkata Sai Kumar Manapragada and PC Icy (*Approach to Simulate the Rainwater Runoff at Site Level Using Rhino Grasshopper*) explain that every social, cultural, traditional, economical, and technological system on earth is either directly or indirectly connected to climate change. Thus, predicting the impacts, risks, and vulnerabilities become necessary to recognize the mitigation and adaptation measures. They present a tool that facilitates the architects and urban designers to make assessment as a part of the early design analysis. The authors explain about the need to integrate the stormwater management during the conceptual design phase for a low impact design (LID) development. The study also demonstrates an approach to avail the extreme year precipitation data and simulated the DTM for the chosen location and its scenarios.

In this paper "*Applications of AI in Health Monitoring of Structures in Potential Seismic Areas—A Review,*" the authors outline the applications of AI in SHM in seismically active areas by evaluating on field, the resistive power of a structure against earthquakes, and simultaneously it is potential to carry forth the services, e.g., in case of multi-story buildings, bridges, special structures, and lifeline structures. Subsequently, the contemporary applications of AI in the field is reviewed, and alongside, the adaptability, sufficiency, and potentiality of those methods to overcome the barriers of the conventional ones are discussed.

Explaining the difficulty in the implementation of 2016 disaster insurance policy (*State-funded Macro Insurance Policy for Disaster Resilience: A Study on National Disaster Insurance Policy in Sri Lanka*), Liyanage et al. explain about key challenges and issues, such as loss adjustment and claim management, delay in processing claims, staff shortage, and lack of clear guidance on the claim process. While mentioning the case of USA after North Ridge earthquake (1994), private sector insurance providers covered 30% of all private and public direct damages and the federal government covered just 20% of total losses and thereby helping state governments rebuild damaged infrastructure. The paper mentions about micro-insurance by accentuating the difference of the same from other types of insurance through the affordability of such insurances by low-income people. Furthermore, micro-insurance provides timely financial assistance following extreme-event shocks, and it reduces the long-term consequences of disasters. Based on a survey, the paper highlights that human activities on the environment have resulted in the changes in the environment which has led to long-term disastrous situations. Moreover, respondents highlighted that as Sri Lanka is facing landslides and floods frequently, the most common reasons for these disasters are continuous heavy rainfalls, lowland reclamation, forest clearance in hilly areas, sand mining in the river valleys, changes, and blocks in waterways, use of mountain areas for construction activities in an improper way, and water storing in highlands, among many other factors.

In this paper *titled Hydrological Analysis for Flood Forecasting at Sg Golok River Basin Malaysia,* Lariyah Mohd Sidek et al. explained about flood warning, which is one of the non-structural measures that have proved to be efficient and cost effective in minimizing the negative impacts of flooding. The authors described how to develop and maintain an integrated flood forecasting and river monitoring system, with flood dissemination, using national network data, telemetry data, radar data, and rainfall forecasts and thus applying the NaFFWS for all the key river basins in Malaysia.

Lariyah Mohd Sidek et al. *(Developing the Flood Risk Matrix for Impact Based Forecasting in Kelantan River Basin, Malaysia)* showed that using the IBF concept and the impact threshold values, the ArcGIS based FRM map can predict the impact in the nearby area of the Kelantan river basin. They explained that when communities can adapt proactively to a flood through early warning and early intervention, injury, distress, and the cost of emergency assistance are bound to decrease. The authors claimed that the impact threshold in Kelantan river basin has been verified and agreed upon by government agencies with local expert authority.

6 Dams and Slope Mitigation

Darshan J. Mehta et al. (*Hydrodynamic Simulation and Dam-break Analysis Using HEC-RAS 5*) carried out dam break analysis of the Ukai dam to generate a breach hydrograph and flood map as a result of the dam-break event under piping and overtopping failure. The process of collecting and preparing data, estimating breach parameters, developing a one-dimensional and two-dimensional unsteady-flow model in HEC-RAS 5 software and mapping of flood propagation are outlined in this paper. The authors claim that computed hydraulic parameters through simulation can be useful for preparing flood hazard risk maps and emergency action plans.

In the landmark paper on *Dam Safety—Living with the Risk of Failure,* David C Froehlich and David Gonzalez Diaz explained that dam-failure floods are almost always more sudden and violent than regular river floods. So, managing the contingencies caused by the failure of a dam and the uncontrolled release of water requires the coordinated efforts of both the dam owning/operating agencies and disaster management authorities. Taking the case study of Hirakud dam, India, the authors used both 1D and 2DH numerical models to assess the consequences of its breach and produced flood inundation maps.

Prabhat Kumar et al. *(Response of Hill-Slope Buildings Subjected to Near-Fault Ground Motion*) analyzed the response of hill-slope buildings under the effect of near-fault pulse type ground motions in the Himalayan region. Through this study, it is found that the large amplitude pulses, primarily related to directivity effect, control the response of medium, and long-period structures, and therefore, the high frequency part of the NFGM plays an important role especially for short-period structures.

The paper by Vikalp Kumar and V. R. Balasubramaniam (*Microseismic Monitoring to Analyze Rock Mass Micro-cracking in Underground Powerhouse to Mitigate Potential Disaster*) explained micro-seismic monitoring (MSM) as an effective technique to locate zones of micro-cracking in the rock mass and further for the demarcation of potentially unstable zones in underground excavation. Based on one year of continuous monitoring of Tala Hydropower Plant, potential unstable zones were identified. Signifying the role of MSM, the authors emphasize that getting valuable information ahead helps auditing the safety measures taken at any site. Therefore, this technique is found to be one of the effective ways to evaluate rock mass behavior before occurrence of any disaster.

Koushik Pandit et al. *(Stability Analysis of a Debris Slope by Micropile Reinforcement Technique: A Case Study from the North-Western Himalayas)* carried out a parametric analysis to assess stability of the slope with single rows of micropiles with different diameters, spacing, and aspect ratios. The results show that the slope stability improves satisfactorily for certain cases. The authors used the slope material and factor of safety of the untreated slope under different degree of saturation and then evaluated by utilizing different limit equilibrium methods for static and pseudo-static conditions. The study finds that micropiles even if installed in just a single row can improve the overall slope stability significantly, and it can be very helpful in reducing the cost of construction since the pile diameter, in-plane spacings, and aspect ratios are optimized and chosen for the desired level of safety factor.

7 Strengthening Measures

Naqeeb U. l. Islam and R. S. Jangid in their paper (*Optimal Design of True Negative Stiffness Damper as a Supplemental Damping Device for Base-Isolated Structure*) described a simple optimization design for NSAD using complex eigenvalue analysis of the system matrix. Optimal parameters for NSAD are developed considering the stability of the system and effective fundamental mode damping. Optimal NSAD is supplemented to MDOF base-isolated shear structure as NSD. A suite of six ground motions consisting of three near-fault (NF) and three far-field (FF) motions are used by the authors. Results of the time history analysis show that NSAD works as efficient supplemental damping system for both NF and FF ground motions in contrast to conventional dampers.

K. M. Shaijal et al. in their study *(Material Uncertainty Based Seismic Robustness Assessment of Steel Moment Resisting Frames)* defined robustness index as the ratio of mean annual frequency of exceeding a given limit state of interest neglecting structural uncertainties to the mean annual frequency of exceeding a given limit state of interest considering all the uncertainties, which is often used to quantify the structural robustness. The study estimates the robustness index in terms of uncertainty robustness index (URI) and corresponding modification factors for design strength reduction factors corresponding to different hazards levels.

In the paper titled *Mitigation of Progressive Collapse of Multi-Storey Steel Building by Providing Chevron Bracings,* the authors evaluated the effectiveness of chevron bracing for mitigation of progressive collapse of a nine-story regular steel moment-resisting building, where the bracings are provided in the alternate bays of the top story. Linear static, nonlinear static, and nonlinear dynamic analyses using SAP2000 software under the middle column removal scenario from the ground floor of the perimeter frame in the longitudinal direction are presented in the paper. Based on nonlinear analysis, it is observed that the provision of bracings contributes to the redistribution of forces and effectively transfers the unbalanced vertical load developed due to the removed column to the adjoining structural members.

Hemant Kumar Vinayak et al. *(Seismic Evaluation, Strengthening and Retrofitting of Schools in Shimla, Himachal Pradesh*) used the integrated approach of qualitative assessment with visual inspection, non-destructive testing, masonry structure evaluation with analytical method for in-plane and out-of-plane safety and the method of capacity demand ratio based on elastic analysis and design for reinforced cement concrete structures. The retrofitting and strengthening of building in seismic zone led to the sensitization of the state disaster management authority of the state of Himachal Pradesh, India. They also discussed about the necessity of developing building resilience of important structures and thus increasing resilience. Through such study, the authors emphasized the need of seismic evaluation of schools in the state to prioritize the retrofit activity across the network of institutions. At the end, the authors recommend that buildings with random rubble masonry can be retrofitted without much hampering functionality of the same.

In a paper presented by Praveen Anand and Ajay Kumar Sinha (*Seismic Strengthening and Retrofitting Techniques and Solutions for an Existing RC frame: An Overview),* it is observed that a large number of RC structures lack the existing seismic demand and they clearly reveals an urgent need to upgrade and strengthening. The paper discussed about different techniques and practices available to strengthen the existing and damaged structures, and it also explains the research gaps along with identifying the scope of future research along with establishing effective retrofitting solutions.

Rohayu Che Omar et al. in their paper titled *Integrated Site Investigation Procedure (ISIP) for Managing Infrastructure Development* described about a tool for the decision makers to determine the condition before taking necessary technological steps; e.g., improve and evaluate desk studies and mapping methods that would allow fast and accurate landslide evaluations to be exercised from national to site-specific for the management of infrastructure planning. The approach, as claimed by the authors, is useful for the evaluation of landslide hazards for land suitability requirements, particularly in Malaysia.

8 Summary

Disaster risk management is essential in modern cities to ensure long-term resilience and sustainability. Resilience includes the ability to withstand short-term risks, such as earthquakes, landslides or industrial disasters, and the ability to adapt to changing long-term conditions, e.g., changes in climate, or the advent of the era of artificial intelligence. Resilience also includes community resilience through public engagement. Disaster risk management includes two components: A quantitative risk assessment and management that is typically done prior to the disaster, and includes countermeasures, including warning systems, as well as public and community outreach and education. The natural disasters should not be considered as unpredictable, transitory events demanding emergency responses, but rather as ongoing risks with life cycles extending over years or centuries whose mitigation and adaptation should be permanently embedded in urban planning and policy. This framing points to the balance required of policymakers: the need to make large-scale investments or to exclude potential economic developments today for the sake of reducing the impacts of future events or, where possible, to enable the two policies to coincide [3]. The widespread application of terrestrial and satellite-based geophysical sensing and of our ability to capture such information through the IoT devices and augmented power computing as well as data analytics have the potential to transform our approaches to system engineering in disaster resilience.

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Disaster Preparedness

Impact of Human Activities Inducing and Triggering of Natural Disasters

K. Sukumaran

Abstract The world is witnessing numerous scientific and technological innovations due to human effort in research and development and at the same time, Planet Earth is stressed, degraded and destroyed in terms of environment, ecology and climate due to global population growth, which is posing a great danger in it its sustainability due to consumption of abundant quantity of natural resources for the needs and necessities of global population. The global population shot up from 1 billion in 1800 to about 8 billion in 2020 creating a precarious situation for the earth in its sustainability as huge quantum of all forms of natural resources are consumed for human needs and in turn producing waste, pollution, depletion of natural resources, loss of biodiversity, emission of greenhouse gases in huge quantum causing global warming and climate change. The repercussion of nature being nature's fury in terms of different types of disasters such as earthquakes, hurricanes, tsunamis, floods, droughts, melting of glaciers, rise in sea level, wildfires, landslides, heat and cold waves, etc., which all cause loss of human lives, destruction and damages to infrastructure, epidemic and pandemic, etc., resulting in huge economic loss to the world. These occurrences are due to huge world population growth, which can be controlled and regulated by governance of the countries on wellbeing of global population and it is practically impossible to make the earth a sustainable one for the present and future generation. The solution for this criticality is to restrict population growth of the developing nations specifically in Asian and African continents, use non-conventional energy resources, implement relevant technology to safeguard the earth to maintain its sustainability by minimising trash, pollution, deforestation, limiting urbanisation, reducing greenhouse gas emissions in preserving the nature. The paper gives a glimpse of human actions which are causing natural disasters and the strategies that are to be implemented by regulations of concerned nations to ensure a sustainable world. Discussion and conclusions are drawn in highlighting the basic responsibilities of all the stakeholders in minimising the occurrence of natural disasters and sustainability of the world are bound to be ensured.

Keywords World overshoot day · Ecological footprint · Global hectare

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1 Introduction

The root cause for all the natural disasters is the unscrupulous explosion of world population growth that endangers the sustainability of the world, affecting life of humans, animals, plants and flora and fauna. The question is why humans are consciously unconscious in having more children that will hamper their life prospectus, education, health, food and safeguards, living comforts and other required amenities to live comfortably is to be deliberated with social sense and responsibilities. India is on verge of overtaking China by population, which is a feat that nobody desires as more population would put the country on back foot in its progress and development. Highlighting specific human activities that cause climate change, environmental degradation, which all triggers the occurrence of natural disasters viz., floods, droughts, global warming, earthquakes, cloud burst, landslides, epidemic and pandemic, famine, etc., results in unsustainable world.

It is emphasised that most viable and judicious solution for the uncertain future of the world is supply vs. demand of materials, needs and necessities of the population and controlling and restricting the population explosion of the developing countries in which India is also one of the countries. Though this vital point looks out of context, considering the main issue of natural disasters that all the stakeholders of the country cannot ignore the responsibilities that are to be exercised in finding the solutions, which has become unmanageable and in minimising the risk of natural disasters and also man-made calamities. A few examples such as generating artificial rains by cloud seeding, which is not yielded desired outcomes though this kind of artificial measures to overcome drought conditions ended up with failures in spite of spending more. This example clearly indicates any artificial means to counter natural disasters will not be successful, economical and viable. Hence, a wise thing to do is to limit the exploitation of nature to meet the needs of huge population. The effect of human actions in catalyzing natural disasters and its severity is explored for maintaining sustainability of the Planet Earth. Application of emerging technological tools viz., AI, IoT, GIS, etc., are helpful in forecasting the occurrence of natural disasters well in advance such that people in the specific area can be alerted for precautionary measures to be taken in minimising the loss of life and also to reduce the destruction and damages caused.

2 Effects of Human Population and Activities on Climate Change

Climate change refers to the variations in atmospheric temperature, precipitation, wind patterns, snowfall, global warming, rise in ocean water temperatures, etc. [1]. Human activities causing climate change are use of fossil fuels for transportation, power plants, industrial needs, etc. Expansion of arable land to increase the food production, urbanisation, infrastructure projects viz., buildings, roads, industries,

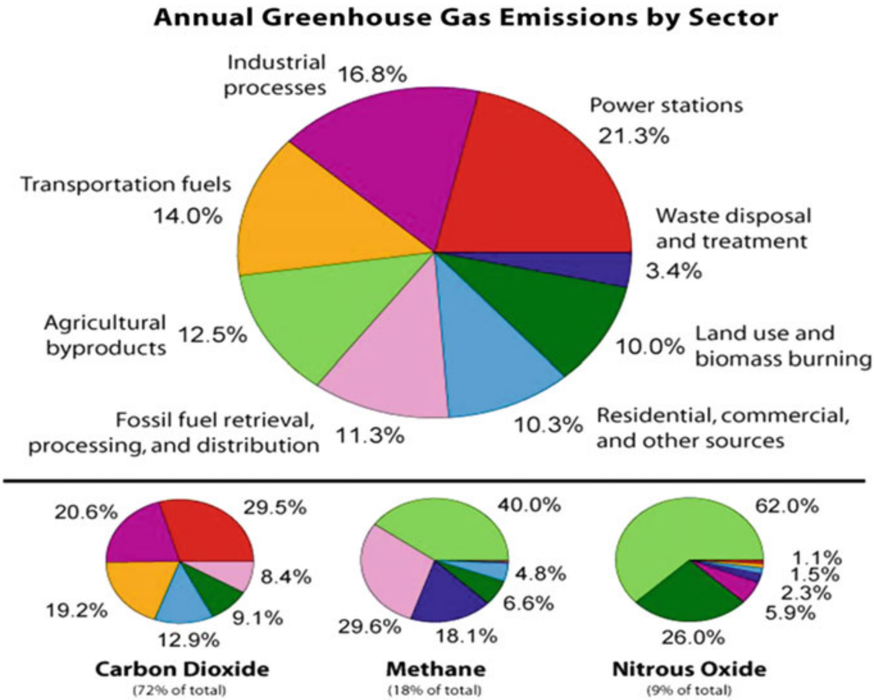

Fig. 1 Sector-wise greenhouse gases emissions [2]

housing, amenities and services, etc., are the induced activities of the humans that cause climate change. Human activities enhance the quantum of greenhouse gases prominently CO_2, CH_4, N_2O, which amounts to 72%, 18%, 8% respectively and the remaining 2% accounting for other gases [2]. Other activities that contribute to climate change are industries, power plants, transportation, agricultural by-products, retrieval processing and distribution of fossil fuels, residential and commercial activities, land use and biomass burning (Fig. 1).

2.1 Extension of Atmospheric Strata Boundary

Apart from human causes affecting climate change, the natural causes such as a change in earth's orbit, the sun's intensity, volcanic activity and circulation of the ocean water are also causing the climate change of the world. The atmospheric boundary, i.e. troposphere, which contains the weather elements such as clouds, air, greenhouse gases and other gases, aerosols, etc., has extended its circumference by greater than 270 m over the past 20 years, between 1979 and 1999 as per investigations carried out in 2003 by Santer et al. [3]. To know what is the cause for this phenomenon, scientists modelled both natural and human factors that are causing climate change and inferred that volcanic aerosols and solar changes are caused by nature and greenhouse gas emissions, aerosol pollutants and ozone depletion by human activities. Also, it has been determined that solar changes during 1900s resulted in warming of stratosphere and troposphere. Actually, the human activities that are increasing in greenhouse gases emissions that generates heat to be trapped within the troposphere and also reduction in ozone in the stratosphere. The combined effects of these two phenomena resulted in greater than 80% of the troposphere circumference change that is also known as ‘tropopause’ [3].

This condition is accelerated by human activities that resulted to:

- Increase in greenhouse gas emissions that cause heat to be trapped within the troposphere.
- Decrease in ozone in the stratosphere resulting in less absorption of sunlight by the ozone layer causing cooling of stratosphere.
- The combined effect of above-mentioned factors is responsible for greater than 80% of the troposphere boundary extension (Tropopause) by 270 m more in its periphery. The average global temperatures have been enhanced by 0.78 degrees centigrade during the last century and intensive in the last 30 years of the century due to increase in global population [4, 5].

As indicated in Table 1 the atmospheric heat due to global warming is absorbed by oceans 93.4% and the resulting effects are El Nino and El Nina, which disturbs the rainfall pattern of monsoons of specific countries such as deficient and excess rainfall causing droughts and floods respectively. Floods perennially occur in certain areas due to ineffective watershed management and also due to loss of vegetation and turf surface of land surface causing soil erosion, reducing storage capacity of reservoirs due to siltation.

From Fig. 2, it is evident that enhanced increase in global temperature and CO_2 emissions caused global warming and the oceans to become more acidic and induced weather events such as hurricanes, wildfires, melting of glaciers, causing rise in sea level. The remedy is adapting renewable energy techniques in lieu of fossil fuels

Table 1 Absorption of heat due to global warming by various identities [6]

S. No	Name of the entity	Percent absorption	Remarks
1	Oceans	93.4	Results in hurricanes, storms, El Nino, El Nina effects
2	Atmosphere	2.3	Global warming and Heat waves
3	Continents	2.1	Warming of terrains
4	Glaciers and Icecaps	0.9	Melting of ice Caps and lead to rise in Sea level
5	Arctic Sea Ice	0.8	
6	Green Land Ice Sheet	0.2	
7	Antarctic Ice Sheet	0.2	

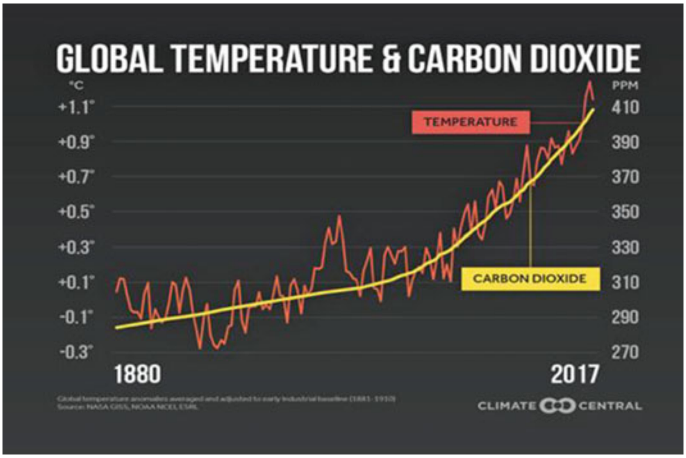

Fig. 2 Correlation between CO_2 and increase in global temperature in atmosphere [7]

to safeguard Planet Earth's sustainability and world's population from ill-effects of pollution and environmental degradation.

3 Effects of Population Impacting on Environmental Degradation

Environmental degradation is explained as deterioration of the environment by consuming natural resources such as air, water and soil (land), destruction of forests and its eradication results in human-animal conflicts (by straying of wild animals in human habitat causing loss of crops, loss of plantation by herd of elephants). Substantial expansion of human settlements due to urbanisation at the cost of forest areas resulting in straying of wild animals in rural and urban settlements in search of water and food in drought conditions. Expanding global population is causing depletion of natural resources viz., land, air, water, forest cover and intensification of arable land for cultivation to produce agricultural products, etc., resulting in environmental degradation. All these human needs are resulting in endangering of the environment, ecology, flora and fauna. The types of environmental degradation are classified as listed [8]:

- Land and soil degradation—due to farming practices, excessive use of fertilisers, pesticides, seepage from landfills, solid waste dumps, etc.
- Water degradation, i.e. polluting of water bodies viz., lakes, rivers, springs, reservoirs, seas and oceans with wastewater, discharge of untreated effluents of industries and discharge of domestic wastewater in water bodies, dumping of garbage and solid waste (plastic and its by-products which are non-biodegradable), etc.

- Atmospheric degradation due to air pollution and depletion of ozone layer.
- Other types of pollution viz., noise pollution, light pollution at commercial and recreational centres (excessive illumination), traffic noise, industrial operation, mining, etc.
- Landfills by dumping of muck and excavated soils from construction projects viz., tunnels, dams, infrastructure development, tailing from processing of minerals and ores and debris.
- Deforestation of forest areas for industries, hydraulic structures, human settlements, etc.
- Natural disasters such as volcanoes, tidal waves, storms, wildfires, etc., causes severe loss of natural resources viz., trees, vegetation, crops, human and animal life, etc.
- Air pollution causes respiratory diseases, skin and eye allergies in all humans, which affects the health of animals and plant species.
- Loss of biodiversity and ozone layer depletion.
- Awareness in avoiding use of plastics and other non-biodegradable products to avoid generation of waste by the concept of reducing, reuse, recycle and reproducing in reducing the carbon footprints.

4 Impact of Human Footprint Causing Natural Disasters

Global human population caused a lot of degradation to the Planet Earth like no other species impacted so much of world's sustainability by depletion of natural resources, polluting environment and atmosphere resulting in global warming and climate change, deforestation, loss of biodiversity, i.e. extinction of plant and animal species. Human footprints of vital resources viz., freshwater use, marine fish capture, forest loss, etc., are shown in Fig. 3. Estimated world population in 2050 is to be 9.5 billion and how the food supply chain, shelter, health, education, water, energy needs can be met with overpopulation as it affects the world in terms of its sustainability and endangering world's environment and ecology and the future human generation needs and necessities.

The earth's overshoot day, i.e. the world's population consumption of earth's viable natural resources for the year 2019, which occurred on 29th July 2019 whereas the earth overshoot occurred in the month of August between 2010 and 2017, that implies that population growth, change in lifestyle, economy, which all govern the consumption of world natural resources in an unsustainable way. The remaining days of the earth after overshoot day indicates that world population is consuming natural resources beyond this date becomes unsustainable that causes environmental degradation. The consumption beyond the viable supply of natural resources results in global warming, climate change and the compounding factors causing natural disasters in various forms such as tornadoes, floods, droughts, etc., due to the phenomenon of increase or decrease of ocean water temperatures (El Nina and El Nino), forest fires, earthquakes due to tectonic movement, volcanoes, tsunamis, landslides, etc., due to urbanisation, deforestation, overconsumption of natural ores, minerals, coal, oil, natural gas and increase in pollution due to industrial activities, automobiles, enhanced arable land, etc., are accounted in determining the overshoot day of the earth every year. For instance, the USA requires resources about five earths as its overshoot day fell on March 15th in 2019 whereas India's earth overshoot day does not occur in a year as its consumption of world's natural resources is 0.7 earth though the population is high but due to poor economic conditions and poverty. The number of earths required in terms of natural resources consumption of major economic nations is depicted in Fig.4 with the world global earth overshoot being determined as 1.75 in 2019 [9, 10].

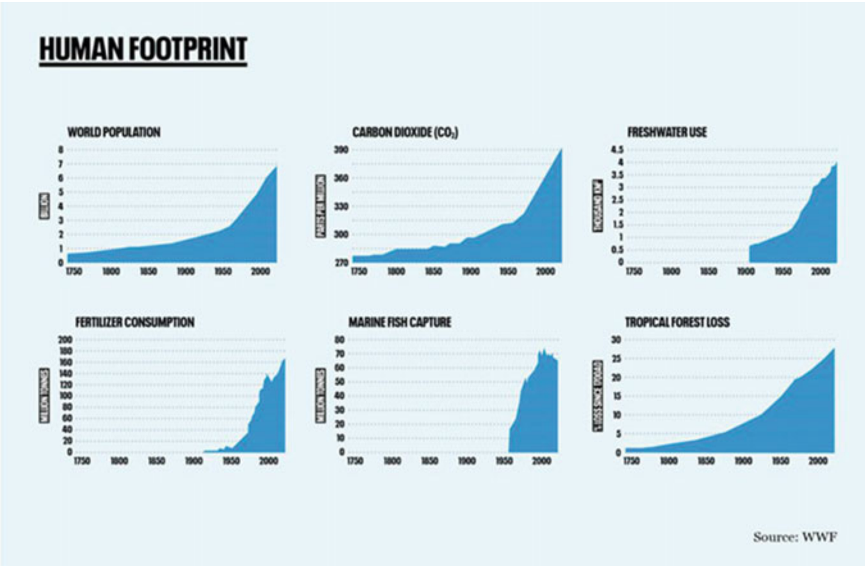

Fig. 3 Global Human footprint showing consumption of vital natural resources and generation of co_2, forest loss [10]

4.1 Capacity of Planet Earth to Support Human Population

World human population is nearing 8 billion and there are limitations in facilitating life-sustaining natural resources that earth can provide to humans. The earth's carrying capacity is defined as the maximum number of species an environment can support indefinitely. Each and every species has a carrying capacity including humans, but humans are a complex species and consumption of natural resources increasing with the increase of the world population. Some of the global human

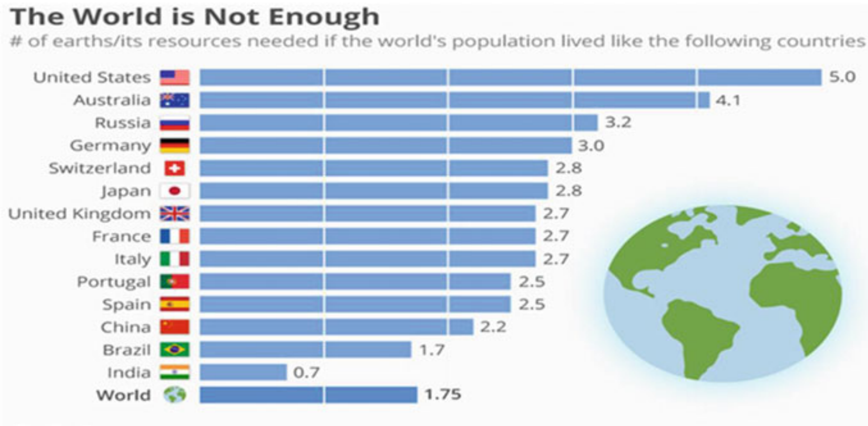

Fig. 4 Consumption of global resources by prominent countries by equating to number of earths [11]

footprints indicating human consumption of vital natural resources and generation of CO_2 are shown in Fig. 4. Hence, human population carrying capacity of earth depends on various factors as listed.

- Future trends in demography
- Availability of natural resources
- Technological advancements
- Economic development.

5 Ecological Footprint (EF)

It is a measurement of anthropogenic (study of the origins of humanity) impact on earth and it determines how much biological capacity is available and how much biological capacity utilised by the world population. Ecological Footprint (EF) is a method of measuring sustainability that refers to the ability of a population to support itself without compromising that ability for the future. Environmental sustainability happens when a population can adhere to a particular lifestyle indefinitely while still meeting the demands placed on the earth. The outcomes of EF are as listed [12]:

- A way of measuring sustainability is EF that is a method of determining human's dependence on natural resources and EF calculates quantum of environment required to sustain a specific lifestyle.
- The EF can be determined for different populations, cities, regions, countries, individuals and for world.
- Unit for EF is global hectare (GHa) that measures the quantity of biologically productive land with productivity equal to the world average.

- An area is considered unsustainable if demand from nature is more than its supply which means land's EF is greater than its biocapacity.

Currently, earth's footprint is 1.75 times of earth to sustain the present population and the prevailing population growth continues then by 2050 three times of earth is required; otherwise in absence of remedial or corrective measures by 2050 global population can get only one-third of earth natural resources. It infers that our next generation will be deprived of required natural resources and the future scenarios are very grim and in turn result in natural disasters or calamities as the nature is distressed by consumption of huge quantity of natural resources, emission of voluminous quantum of pollution, degradation of environment, ecology and flora and fauna. At present the world population is encountering COVID-19 pandemic, which already caused globally about 1.9 million deaths and how long it will prevail is not known. The world economy is affected by the pandemic, which is in descending trend and normal life of people is severely affected.

How to manage the catastrophic situation of the earth is suggested by Joel Cohen with three propositions as proposed [10]:

- Improving technology to minimise the consumption of natural resources by the world population.
- Simpler solution is to slow down the population growth as advocated legally by China as an example.
- Changing the global population culture is consuming the natural resources conservatively as the trend of USA accounts for five times of earth resources consumption.

Joel Cohen suggests that all above listed three paradigms should be attempted to solve the environmental crisis of the earth coupled with human responsibilities to have small families, improving economy of developing countries, educating men to realise the situation and future scenario and also empowering women folks. Apart from human initiatives, technological innovations and advances can play a supporting role in achieving a sustainable future of the world.

Ecological footprint is measured in terms of global hectares (GHa) which means the amount of biologically productive land with productivity equal to the world average. Ecological footprint is the metric in assessing human dependence on natural resources by determining how much quantum of the environment is required to sustain a specific lifestyle. Otherwise, it is known as demand vs. supply of nature in terms of environmental sustainability. Specifically, the ecological footprint measures the quantum of 'biologically productive' land or water that enables the population to sustain itself.

The measurement of ecological footprint is based on resources required for the population of a country or a region or for the world to produce goods and also to clean up the waste generated by consumption of goods. The consideration for calculation of ecological footprint includes arable land, pastures and parts of the sea that consists of marine life. The equation to determine the ecological footprint as given by Tiezzi et al. [13]:

$$EF = \sum T_i / Y_w \, (EQF_i)$$

where T_i = annual amount of tons of each product '*i*' consumed in a country relative to the number of goods were produced in the world on average.
Y_w = yearly world average yield for producing each product EQF_i = equivalent factor for each product *i.*

'Global footprint network' (GFN) a non-profit organisation, which associated with 100s of cities, businesses and other entities in promoting EF as a metric of sustainability, determines the per capita global footprint was 2.8 GHa in 2014 and the global biocapacity corresponding year was 1.7 GHa per person.

The total ecological footprint for specified activities of population is measured in 'global hectare' (GHa). Presently, the biosphere has about 11.2 billion GHa of biologically productive area, which is one-fourth of the planet's earth surface. The biologically productive hectares include 2.3 billion hectares of ocean and inland water surface and 8.8 billion hectares of land. The land area is consist of 1.5 GHa cropland, 3.5 GHa of grazing land, 3.6 GHa of forest land and 0.2 GHa of built-up land. The total area of 11.2 GHa area is biologically productive on which population and other species of the world survive for food footprint. Considering world population as 8 billion and world biosphere of 11.2 GHa, then per person the bioproductive hectare per person is 1.4 Ha, which indicates that the world population consumes 1.4 times of the Planet Earth's natural resources, which results in environmental degradation including depletion of bio-diversity, flora and fauna. Humans started using fossil fuels (crude oil, coal, natural gas) on a large scale since the time of industrial revolution, which began around 1760 AD. Prior to the industrial revolution, about 80% of the world population inhabited rural areas as farmers; but after the industrial revolution, many people in million migrated to urban areas for jobs in industries. This revolution paved way for explosion of inventions and innovations. This transformation initiated large scale cnsumption of fossil fuel energy around the world and resulted in emission of greenhouse gases and in turn raising the temperature of the atmosphere leading to global warming causing climate change. The overshoot day of different countries is as shown in Fig. 5.

6 Prominent Ways of Triggering Natural Disasters

Apart from causing harm to the nature, environment and ecology in terms of consumption of various natural resources by human actions for the needs of living, they can also trigger a sudden natural disaster such as mud volcanoes, earthquakes, vanishing lakes, floods and hurricanes to name a few as prominent ones. The examples of human activities triggered natural disasters are briefed below [16]:

a. **Mud volcanoes**: Mining activity**,** erupted mud slurry oozing out about 7000 to 15,000 m_3 per day from a gas well near Surabaya of East Java, Indonesia

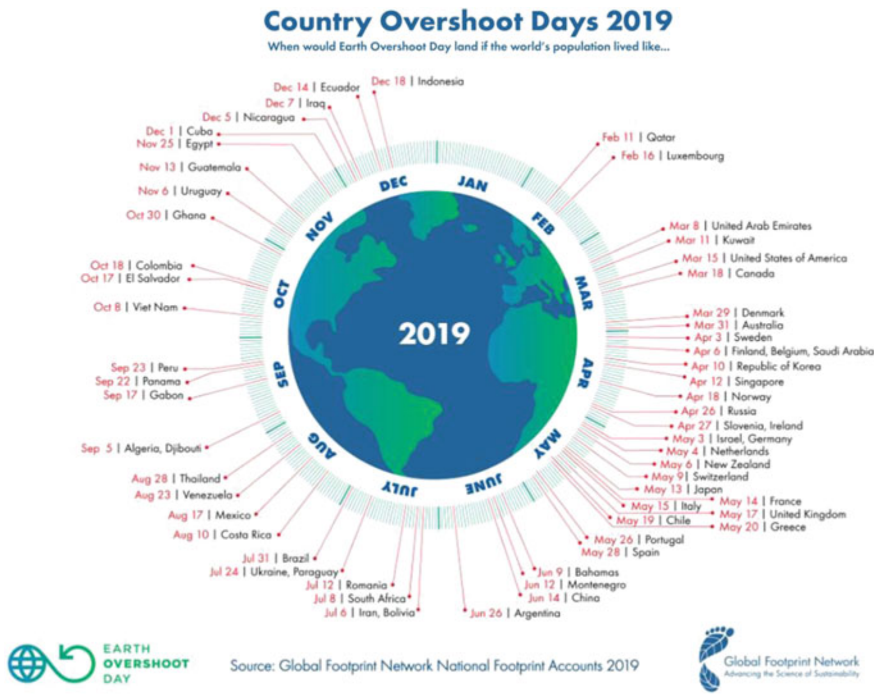

Fig. 5 A country's overshoot day is the date on which earth overshoot day would fall if all of humanity consumed like the people in this country [14, 15]

that resulted in the displacement of eleven villages. The concerned firm dealing with gas well work made the allegation that mud volcanoes were caused due to earthquake that occurred about 40 hours earlier at a distance of 250 km away. But independent geological investigations revealed that the firm's claims are false as the ground tremors caused by drilling of oil or gas wells make the ground shake or vibrate causing the flow of mud volcano releasing the slurry.

b. **Earthquakes**: Frequent oil drilling operations at North Sea caused tremors in the crust beneath the North Sea and also mining can increase the frequency of tremors due to the redistribution of normal stresses present in the rocks may be potential man-made earthquakes. Dams are the most vulnerable structures to cause a quake as storage of huge quantum of water at one place, which increases the pressure on fractures beneath the surface of the earth due to lubrication effect of water causing slip of fractures and faults. For instance, largest dam induced earthquake with a magnitude of 7.5 struck the area that occurred in Koyna, Maharashtra State, India on 11th December 1967.

c. **Vanishing Lakes**: Lake Peigneur in Louisiana on 20th November 1980 was sucked into the ground in an enormous size whirlpool. The reason is that the lake's plug was pulled when Texaco oil company rig drilled into a salt mine directly beneath the lake. This made water drain into the mine, filling the shafts and dissolving the salt then sucked down the oil rig and eleven barges. This incident permanently changed the lake's ecosystem. After a few days, water flowed back from the Gulf of Mexico turning the freshwater lake into a brackish, saltwater one.

d. **Floods**: On June 9, 1972, more than 35 cm of rain that is a year's amount of rainfall occurred in six hours over the Black Hills of Western South Dakota, USA. The cloudburst was due to cloud seeding, which caused "Rapid Creek" to overflow and the Canyon Lake Dam to burst and caused huge floods downstream of Rapid City. The calamity resulted in death of 200 people, injured 3000 people, destroyed 1300 houses and the overall economic loss was $ 160 million in damage to Rapid City. The exact reason for this calamity was the scientists were conducting cloud seeding while a storm was set in, which caused the floods.

e. **Hurricanes**: In 1960, U.S scientists attempted a "hurricane seeding" project named "stormfury" to demonstrate to disrupt the structure and energy of a hurricane by seeding the atmosphere. The aim was to change the direction of approaching storm to prevent its landfall on the mainland; but this act would attract legal complication by the affected nation/s due to the change in direction, which delineate storm direction and adjacent or neighbouring countries may be affected. Later this task was abandoned as it was not successful.

7 Disaster Management Strategies

Natural disasters have increased its frequency of occurrence and severity, causing devastating loss and destruction to the humans, infrastructure, crops, plantations, including livestock and animals (in case of wildfires). A variety of reasons behind these developments being such as population growth, climate change, migrating habitation trends, urbanization, etc. As per the UN report 2009, the occurrence frequency of natural disasters increased more than 60% from 2003 to 2005 compared to 1996 to 1998. The 'worlds watch institute' states that in the year 2007 there were 874 weather-related natural disasters throughout the world with 13% increase in occurrence to 2006 and also highest numbers occurred since 1974 [17]. Hence, it is imperative to develop tools, processes, effective practices to manage risk of natural disasters with the use of relevant technological tools such as remote sensing, GIS, GPS, IoT, Big Data, database management, information management from various sources and also to organise and act collaboratively to help the affected people, damage mitigation and also rehabilitation after the devastation.

Making use of advanced information tools, techniques, communication systems can minimise the loss of life and adapt effective building technologies in the zones of disasters, where the occurrences of disasters are frequent. Swift organising the rehabilitative measures and mobilisation of relief materials, medical services, rescue teams, etc., in case of critical and emergency conditions is essential in minimising the loss of lives and the devastation. The use of modern information and communication technologies (ICT) systems can help in knowledge sharing, situational analysis and optimising the collaborative actions in disaster management.

8 Discussion

It is evident that technological development, innovations, automation, etc., transformed the world to become dynamic and smart. All this progress is accomplished by utilising natural resources in different forms such as ores, minerals, water, air, soil, sunlight, etc., for humans' needs and necessities to live and also to lead life. The unsustainable population of the world particularly in developing countries causing environmental degradation, ecological destruction, urbanisation, deforestation, burning of fossil fuels, natural gas, coal, resulting in the emission of greenhouse gases specifically CO_2 in huge quantum, increase in arable land to produce more food for the growing population, increase in energy requirements, etc., causes environmental degradation and destruction of nature by overexploitation of natural resources such as fossil fuels, gas and coal for transportation, industries and power generation. Apart from this, infrastructure development such as buildings, roads, dams, industrial structures, etc., consumes a lot of natural resources for growing population needs of the world. All these human activities are at the cost of natural resources and destroying nature that results in perturbing nature causing natural disasters in various forms. For instance sinking of oil, wells vibrate and shake the land causing fissures in rock strata and the outcome being earthquakes. Same is the case with building of huge dams with large quantities of impounding water is the potential danger in the occurrence of earthquakes. For instance, Koyna dam collapse was the cause due to the occurrence of earthquakes.

Pitfalls due to environmental degradation also result in pandemic and epidemic hazards and presently the world is badly affected by the COVID-19, which resulted in huge causality of human lives and shaken the world economy as a vaccine for its treatment is just produced by scientists. Conservation of natural resources is very vital for the sustainability of world with a sustainable global population. China implemented population control with stringent regulations and controls and reaped the benefits to become economic superpower with progress in manufacturing of goods and also R & D in many domains including space technology. It is imperative both progress and destruction of the world is with human deeds and the governance of developing countries shall formulate policies, regulations and controls in limiting population growth to ensure the sustainability of Planet Earth and educate the people to have awareness on having small family can benefit all in living a comfortable and healthy life with needed resources and also in safeguarding the sustainability of the world as good world citizen without any prejudices with open mind and caring for everyone's wellbeing.

9 Concluding Remarks

- Global population by 2020 was 7.8 billion and will become 8 billion by 2024. On average every year 74 million people are added to the total population that needs huge quantity of natural resources in various forms that causes depletion of natural resources, resulting in environmental degradation, generation of waste, greenhouse gases predominantly CO_2, pollution of air, water, land, deforestation due to urbanisation as presently more than 60% global population is inhabited in cities making it as hot spots in terms of emission of heat, traffic pollution, etc., are causing distress and damage to the nature, which in turn resulting in causing of natural disasters and calamities. As per 2019 data, the global average economic loss due to all types of natural disasters amounted to $232 billion.
- The world population is unevenly distributed as developed countries have less population, i.e. 1 billion compared 6.8 billion people live in developing countries situated geographically in continents of Africa and Asia. Most of the developing countries are economically poor due to overpopulation with lack of basic amenities like nutritious food, potable water, sanitation, housing, infrastructures such as roads, communication facilities, medical care and also due to poor economic growth and development.
- The disparity of population, economy, lifestyle, growth and development, education, basic amenities, awareness, etc., that are prevailing in the developing countries impacts the people and suffer from basic needs for living and bearing more children in the belief that more children can earn revenue is the misconception possessed by people of such countries generate child labour and deprived of education makes them become unskilled labour force, who are not aware of causing harm to the nature by cutting trees for firewood and not preserving the environment are some of the man-made destruction of nature.
- The pitfall due to the precarious situation of poor governance of developing countries without appropriate policies for wellbeing of people, societal concern and without futuristic perception of growth, development, which all makes the people become economically poor as no awareness of destroying of nature and its repercussion in occurrence of natural disasters.
- Infrastructure such as dams, roads, transportation facilities, telecommunication, industries, education, exports and imports of goods, other various developments are impairing nature by the requirement of natural resources for the development of a country. But the quantification of all these parameters is based on the quantum of population, societal needs and necessities, lifestyle and also geographic conditions. India being a tropical country with ample provision of natural resources exception being less oil, can exploit the renewable energy resources to generate power and should reduce its dependence on oil as being third largest crude oil importer in the world, amounting to Rs. 8.81 lakh crore ($120 billion) for 228.6 million tonnes of crude as per 2018–19 data. Transportation, power generation and industrial sectors consume substantial quantum of oil and gas and it is worth

minimising the oil use in transportation by substituting electric vehicles and industries utilising solar power in reducing the carbon footprint of the country. New Delhi is listed as the topmost air polluted city in the world because of stable burning and also automobile emissions, etc.

- It is a well-known fact that 1 ton of cement produced emits 1 ton of CO_2 and the research is in progress by reducing this by 25–30%.
- Finally, the governing factors in ensuring sustainability is the awareness of people and the societal concern and also wellbeing of every world citizen in playing role in minimising the generation of pollution, waste, conserving water and other natural resources in safeguarding the Planet Earth from its destruction and also to ensure a sustainable world.

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Implementation of Build Back Better Concept for Post-Disaster Reconstruction in Sri Lanka

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Abstract Post-Disaster Reconstruction (PDR) can be considered as an opportunity to undertake improvements in lifestyle, safety, economy or environment of disaster affected community as it deals with high level of media attention, technical and expert advice and financial assistance after a disaster. Such improvements, which are carried out during the PDR phase to reduce the risk of future disasters with development measures is termed Build Back Better (BBB). This concept invites the disaster affected communities to set on better and safer development paths by seizing moral, political, managerial and financial opportunities offered by a disaster to the governments. BBB concept was introduced to Sri Lanka at the recovery effort of Tsunami in 2004 and since then had contributed to many Sri Lankan PDR projects. However, studies on BBB in Sri Lanka are only limited to the recovery activities of Tsunami in 2004 and there is a necessity of reviewing the progress of implementation of this concept to other Sri Lankan PDR projects conducted recently. Hence, this study aims to investigate the application of BBB concept for recent landslide PDR projects to learn the appropriateness of BBB to current Sri Lankan context. A case study research strategy has been adopted to proceed with the study following the qualitative research approach. Semi-structured interviews from relevant authorities and community members were employed as the data collection method for case studies. The data analysis was selected as manual content analysis focusing on the major BBB components; Disaster Risk Reduction, Community Recovery and Implementation. This study determines the practices of BBB in PDR projects to accomplish disaster risk reduction and community recovery through effective and efficient implementation of PDR in Sri Lanka. Moreover, the challenges while implementing BBB in Sri Lankan PDR have been identified with reference to the community. Further, this research suggests the necessity of identifying strategies to overcome the challenges of BBB implementation in order to succeed in future PDR projects. Finally, the lessons learned from Sri Lanka contribute to the knowledge of implementing BBB for PDR worldwide.

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1 Introduction

In recent decades, many catastrophic events have occurred and caused severe damages to both communities and property worldwide. According to the United Nations Office of Disaster Risk Reduction [36], disasters are identified as serious disruptions to the functioning of a community that cause human, material, economic and environmental losses. Following a disaster, great deal of attention is paid to the Post-Disaster Reconstruction (PDR) activities as it helps to rebuild the affected community. Hidayat and Egbu [12] consider PDR as a key for disaster mitigation and preparedness, which can influence the vulnerability for future disasters. Further, Thurairajah, Amaratunga and Haigh [34] assert that PDR can be used as an opportunity to re-plan the community. However, PDR is a complex process that deals with several challenging tasks due to multi-sectoral involvement and high demand for significant skills and resources [13].

Common challenges found in reconstruction projects are funding and finding proper relocations for disaster affected communities [11, 36]. Fraud, corruption and waste of project funds are a few issues associated with the funding of PDR projects [13]. Inadequate supply of resources for reconstruction and potential disruptions in the resourcing process can be seen during the construction stage of many PDR projects [3]. Non-availability of labourers and materials is also a huge challenge, which hinders planned progress of housing reconstruction [26].

Due to the above challenges, different frameworks and approaches for the practice of PDR activities were developed by researchers which can be adopted in different, specific PDR situations [2]. Build Back Better (BBB) concept is one of such successful approaches specifically introduced for PDR projects. BBB has the ability to reduce the risk of future disasters by integrating with the development measures [18]. This approach not only restores what existed before, but also sets the communities on a better and safer development path by seizing moral, political, managerial and financial opportunities offered by the crisis [4]. Since the Tsunami in 2004 which resulted in extensive damage to South Indian region including Sri Lanka, BBB has been used to describe a variety of disaster recovery goals [9]. Recovery effort of Tsunami in Sri Lanka also had contributed to the rise of BBB concept in PDR. Since then BBB concept was applied for many Sri Lankan PDR projects that have been implemented not only for tsunami but also for landslides and floods. However, the success of BBB implementation in PDR in Sri Lanka has not been assessed properly yet, which is determined through the success of current practices and their issues [20]. Therefore, this paper investigates the current practices and challenges of BBB implementation of PDR in Sri Lanka.

2 Literature Review

2.1 *What is Build Back Better?*

"Build Back Better (BBB)" is a term that surfaced after the Indian Ocean Tsunami happened in December 2004. This concept was introduced to enhance the effectiveness of disaster response activities in future disasters expressing best practices that stakeholders should follow in the recovery stage after a disaster. With the attention received to the BBB, researchers tried to define the term in different ways [20]. Following Table 1 is developed by evaluating identified definitions of different authors from past literature.

Among the above definitions, Mannakkara's and Wilkinson's definition is broadly accepted and three main components of BBB as per that definition are as follows:

Disaster Risk Reduction (DRR)—DRR in BBB concept is extremely important to increase the resilience to disasters, where reason for disasters is identified as the built environment in most of the cases . Accordingly, resilient communities can be created by reducing the disaster risk through reconstruction of the built environment.

Table 1 Definitions of BBB

Definitions	Key Areas	Source
A new kind of recovery that not only restores what existed previously, but goes beyond, seizing the moral, political, managerial and financial opportunities the crisis has offered governments to set communities on a better and safer development path	• Safety, Security and livelihoods • Roles of Stakeholders • Fairness and equity • Disaster Risk Reduction	Clinton's Key Propositions [4]
A concept that incorporates adopting a holistic approach to improve a community's physical, social, environmental and economic conditions during Post-Disaster Reconstruction (PDR) and recovery activities to create a resilient community	• Disaster Risk Reduction • Community recovery • Implementation	Mannakkara and Wilkinson [20]
An approach of recovery, rehabilitation and reconstruction to increase resilience of nations by adopting disaster risk reduction measures	• Disaster Risk Reduction • Stakeholder management • Mechanisms for recovery	Sendai framework for disaster risk reduction (2015)
A concept to convert disaster to an opportunity	• Community Participation • Women's Empowerment	Fan [9]

Community Recovery—The main goal of a PDR project is to restore community's functioning to put people's lives back together after the severe disturbances by a disaster. According to Mannakkara and Wilkinson [20], two principals were identified under community recovery as economic recovery and social recovery. Hence, most of the guidelines for BBB promote human welfare in PDR, to recover the community socially and economically [38].

Implementation—The parties involved in reconstruction and recovery activities after a disaster encounter numerous challenges during the implementation. Stakeholder management and legislation and regulations related to PDR are identified as two principles under the implementation [20].

2.2 Build Back Better in Sri Lanka

Observations made during Post-Disaster Reconstruction (PDR) in Sri Lanka had been used to develop different types of Build Back Better (BBB) frameworks [4, 19]. Accordingly, PDR procedures in Sri Lanka has provided great contribution to establishment of BBB in the world.

With the establishment of BBB concept, government of Sri Lanka has adopted it after the implementation of Sendai framework, which identifies BBB as one of the priorities for Disaster Risk Reduction (DRR). Therefore, DRR measures were identified in most of the PDR projects conducted by the NBRO while planning and constructing resettlements [24]. Although most resettlement projects have given priority to DRR, Post-Disaster Recovery Plan for floods and landslides in 2017 has identified an implementation program, which also includes institutions mechanism for PDR [21]. The main policy of this plan is to achieve community recovery.

Institutional mechanism of owner-driven approach for post-disaster housing reconstruction in Sri Lanka professed more towards the stakeholder management principle suggested in the BBB [35].

Even though the above measures have been taken by the Sri Lankan government in order to promote BBB, there are several loopholes while implementing them, which resulted in unsuccessful PDR outcomes.

3 Research Methodology

Research methodology elaborates the process of achieving the aims and objectives, for the established research problem using a methodological framework including research approach, research process and research techniques.

Three research approaches have been acknowledged by Creswell [5] as qualitative, quantitative and mixed approaches. Among them, qualitative research approach was followed for the data collection because according to Creswell [5] it is the best approach when the research problem is formulated to understand a concept. Build

Back Better (BBB) is also an emerging concept, which needs to be understood by the world to apply in recovering process from a disaster. Therefore, the research problem is constructed as "How does the BBB concept adopt in PDR projects in Sri Lanka?" and the aim is designed 'to investigate the application of BBB concept for PDR in Sri Lanka'. Qualitative research approach is most appropriate for cases evaluating social, attitudinal and exploratory behaviours and beliefs (Naoum 2007). As this study is based upon the opinions of the beneficiaries of PDR and the authority, it is focused on subjective data. Therefore, the qualitative approach was selected as it would enable to explore BBB concept and its application in Sri Lanka in a detailed manner.

A case study research strategy is adopted to analyze the implication of BBB practices in different types of PDR projects. According to Yin [41], a case study approach is suitable for exploring the nature of the process and obtaining a deep understanding of the process. Consequently, case studies are used to explore contemporary or real-life scenarios, where procedures can be identified. The implementation of BBB in PDR is a contemporary scenario, which can be explored as in a real-life situation. Further, in case studies, researchers are allowed to collect detailed information over a sustained period of time [5]. This study intends to gather opinions and experiences of the community and the authority regarding BBB implementation in detail within a limited time period which proves case study as the most appropriate research design. Moreover, Teegavarapu et al. (2008) have pinpointed that case study is an ideal strategy when the research problem is "why" and "how" type question. Since this research problem is putting the research in assessing opinions with the question starts with "how", case study strategy is more suitable.

Accordingly, three PDR projects have been selected as cases expecting different results due to their different nature, where one project was conducted by the NBRO and others by the local government authority. The case profiles are described in Table 2.

Data collection was conducted through semi-structured interviews, where guideline was prepared to determine the practices of BBB in PDR activities in Sri Lanka. As per Table 2, the participants were the community, who are the beneficiaries of PDR projects and the representatives of authorities, who are involved in planning, designing and managing PDR projects. Manual content analysis was utilized for the data analysis since the researcher wanted to get more familiar with the data set and the data gathered from the interviews were manageable.

4 Data Analysis and Findings

The practices of each Case are analyzed under three main components of BBB concept: Disaster Risk Reduction, Community Recovery and implementation. The opinions and the experiences of the respondents regarding BBB practices under each element were investigated through semi-structured interviews.

Table 2 Case study profile

	Case 1	Case 2	Case 3
Leading stakeholder	District Disaster Management Unit (DDMU)	Ministry of Disaster Management	Ministry of Disaster Management
Reconstruction approach	Donor driven	Owner driven	Owner driven
District	Badulla	Kalutara	Galle
Disaster type	Landslide	Landslide	Flood
Community involvement	No involvement	Involve in construction	Involved in land selection and construction
Respondents	• Representative of DDMU (C1R1) • Disaster management officer of Divisional Secretariat (C1R2) • Technical Officer of Divisional Secretariat (C1R3) • Beneficiaries of PDR projects (C1R4, C1R5, C1R6)	• Planning officer of NBRO (C2R1) • Disaster Management Officer Divisional Secretariat (C2R2) • Village Officer of Relocated area (C2R3) • Beneficiaries of PDR projects (C1R4, C1R5, C1R6)	• Engineer at NBRO (C3R1) • Disaster Management Officer Divisional Secretariat (C3R2) • Engineer at District Secretariat-(C3R3) • Beneficiaries of PDR projects (C1R4, C1R5, C1R6)

4.1 Case 1- PDR Project Implemented Due to Landslides in Badulla

Disaster Risk Reduction

According to C1R1 the most challenging task at initial phase in order to reduce the disaster risk was to select the most suitable land for living while avoiding disaster risk. Supporting C1R1, C1R2 stated also that, "there were only a few options for relocation sites since nearly half of the Badulla district (the area affected by landslide) already has been gazetted as landslide risky areas".

Even though selected land has less risk of landslides, still it belonged to hilly areas due to the geographical conditions of Badulla as per the C1R3. Therefore, the respondent further stated that "houses were constructed in 'step by step' formation to reduce the risk by reducing the slope gradually". Moreover, rubble retaining walls were used to restrain the soil between two steps. It was observed that roads to houses also have been concreted and proper drainage system has been established in order to avoid soil erosion.

C1R2 stated that all the houses in the project were constructed according to a standard design from NBRO. C1R1 commented as "In these houses, all the openings were constructed in the front wall and back wall to avoid the disruptions to the flow of wind. This shape reduces the load of wind on the walls of the house."

Majority of the respondents from the authority acknowledged that the design is simple to construct, cost effective and most importantly resilient to forthcoming disasters.

Community Recovery

Community recovery in BBB is upgrading living standards of people affected by disasters. Recovery effort in Case 1 has failed to fulfil community needs according to C1R4 and C1R5. After the landslide, lifestyles of the affected people were completely changed. C1R5 described that most of the victims were left with nothing, except for what they were wearing during the disaster. They had lived in relief camps for more than two years with the help of the donations they received. Majority stated that they couldn't engage in their previous livelihoods due to relocations.

Despite the authority being happy about the simplicity of house designs, community members were dissatisfied with the insufficient space. C1R6 mentioned that "we were used to raising animals and do cultivations previously. The current space is insufficient to engage in those activities". Similarly, C1R4 complained that "Previously, at least we had our cultivations to cover our daily meals. Now we had to get all the supplies from markets which is costly and unhealthy".

C1R1 and C1R2 mentioned consideration of proximity to some other tea estates, which also had failed due to non-availability of job vacancies. Nevertheless, some new opportunities were emerged for tourism due to the attractive nature of the relocated site. However, despite these opportunities, many families failed to recover in new settlements due to the economic issues and moved back to disaster vulnerable zones according to C1R1.

When considering the social recovery, C1R2 stated that "community hall and a building to conduct a preschool were constructed for the usage of residents". Even though their intention was to re-establish the social life, as per the C1R4 and C1R6, the social facilities were rarely used by the residents.

Implementation

The project in Case 1, has been started with the government approval for reconstruction of each house with a 12 lakhs budget per house. The respondents further explained that the site was selected according to the disaster risk analysis report from NBRO. C1R3 explained about the design as "NBRO has designed houses with disaster resilient features to reduce the disaster risk in the resettlement."

C1R1 elaborated that "Financial allocation was done only for materials as army had volunteered to offer the labour force." No community involvement could be observed in this project. C1R4 and C1R5 appreciated it by saying "government had provided us fully completed houses with each a cupboard, gas cooker, water filter and gas cylinder".

4.2 Case 2-PDR Project Implemented Due to Landslides in Kaluthara

Disaster Risk Reduction

C2R1 stated that the aim of this project was to provide resilient houses hence, they were constructed in an area safe from disasters. At the initial stage, the selected land was investigated by NBRO and ensured as free from disasters. According to C2R2 land development process was conducted by the Divisional Secretariat and following measures were taken to reduce the disaster risk in Case 2.

- Lands were subdivided considering the sloping angle. Only the lands with slopes less than 15° were selected.
- Surface drainage system is designed with tolerance to the surface drainage capacity.
- Access routes were designed parallel to the contour lines and adequate culverts and drains were included to every blocked valley.
- Bottom of drains was concreted to minimize soil erosion and water infiltration.

C2R5 stated that awareness programmes were conducted by the Kalutara District Disaster Management Unit with the assistance of NBRO to make people aware of the resilient housing construction and its benefits. However, C2R2 has stressed out that "community has no idea over the importance of the resilient features. As an example, majority thought that building columns and beams with reinforcement which increase the strength against the disasters is a useless additional cost."

Allowing beneficiaries to design their own house was a key feature of this project. However, every design should be approved by the NBRO under the criteria of having minimum disaster resilient features. C2R4 described that "NBRO guided us to design layouts with resilient features. A number of resilient features for foundations, columns, beams, walls, roofs were introduced by NBRO referring to their guidelines in NBRO [22]. "NBRO suggested these resilient features to be included in our designs. Even though they are cost-consuming we had to comply with them to get the approval for the house design" stated C2R5.

Community Recovery

In Case 2, recovery measures were considered to some extent. C2R2 stated that "most of the beneficiaries are from rural areas." Therefore, Divisional Secretariat has considered the criteria (Less than 2.5 km to town centres, less than 0.5 km to roads, access to water and electricity) when selecting the land.

Majority of the respondents were used to work in plantations or factories near previous locations. Relocation has made many difficulties in going to their previous work according to C2R5 and C2R6. The project is located near to a bus route, which had busses running to town three or four times a day. This was very helpful to the community for their daily lifestyle.

C2R6 has mentioned a community programme called "Grama Shakthi" conducted by Divisional Secretariat office to educate them about gardening. It was conducted to provide new opportunities to housewives to earn income while staying at home. This type of programme can be identified as good BBB practice to provide economic recovery for disaster affected people. Nonetheless, C2R2 explained that "Gardening programmes were not that useful since we do not have enough space for gardening in our lands".

In the resettlement, there were people from different areas who had been given a good opportunity to make new relationships, commented C2R5.

Implementation

Implementation framework has been published by the NBRO for resettlement programme of landslide and flood victims in 2017. Reconstruction process adopted in Case 2 has illustrated in the following Fig. 1.

NBRO, Divisional Secretariat and beneficiaries are direct stakehsolders identified in implementation of Case 2. In addition to them, some other government institutions have been involved in reconstruction process according to C2R1. Responsibilities of stakeholders have been identified in the implementation framework prepared by the NBRO. According to C2R2, "identification of roles and responsibilities at the initial phase helps to implement the project efficiently". Active participation of all the stakeholders is needed for the successful completion of the project.

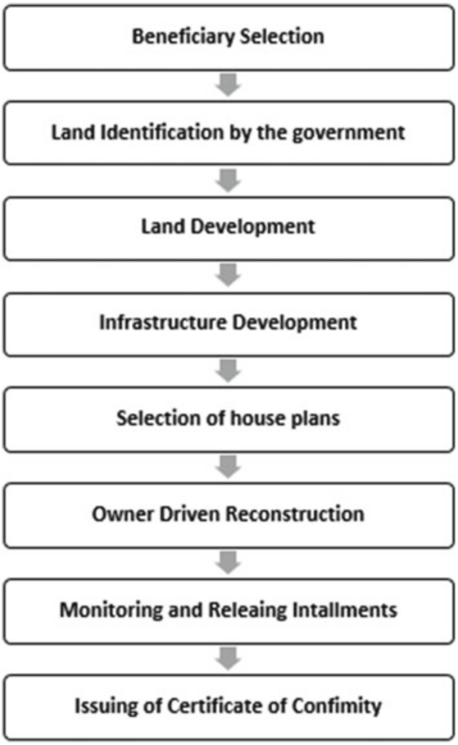

Fig. 1 Implementation process adopted in Case 2

4.3 Case 3-PDR Project Implemented Due to Landslides in Galle

Disaster Risk Reduction

According to C3R1, the main feature of Case 3 was that the beneficiaries were allowed to select their own land. The selected land then should be approved by the NBRO as a hazard-free zone. With the approval of NBRO, Divisional Secretariat office had released the funds to buy the land. As per the C2R2, "this procedure is the most productive way to select the land so far which covers many aspects of disaster risk reduction". NBRO had provided designs for construction of disaster resilient houses. Resilient features conducted in Case 2 were included in the designs of this project as well.

Some of the houses in this project were located in a hilly area, where they were exposed to strong winds. C3R5 stated that "additional nails are used in the roof structure to strengthen the roof against heavy winds". Accordingly, NBRO had provided a number of specifications to build resilient houses in the new location.

Community Recovery

In Case 3, authorities were still unable to provide water, electricity and access road facilities to the beneficiaries as complained by C3R4, C3R5 and C3R6.

Furthermore, C3R5 stated that distance to the closest main road or bus route is more than 1 km from the resettlement which affected negatively for their livelihoods and daily lifestyles. C3R2 stated regarding the issue as "new road is proposed to be constructed from another direction which reduces the walking distance of residents to a bus route". Accordingly, community recovery practices were barely identified from Case 3.

Implementation

Reconstruction process of Case 3 is almost similar to that of Case 2. In Case 3 beneficiaries have been involved in the land identification, which has reduced the responsibilities of government. Divisional Secretariat only participated in acquiring the land by paying the landowner after getting the recommendations from NBRO. Even though land development is identified in reconstruction process, it was neglected by the authorities when implementing Case 3. Infrastructure development was also a part of reconstruction process, which had been ignored by the Divisional Secretariat office staff. Responding to those issues C3R2 stated that "infrastructure and land developments were cost and time consuming processes which we couldn't consider within the limited period."

5 Discussion

The discussion on Build Back Better (BBB) practices implemented in Post-Disaster Reconstruction (PDR) projects in Sri Lanka, is conducted under main three concepts as Disaster Risk Reduction, Disaster Recovery and Implementation.

5.1 Disaster Risk Reduction

Empirical study shows that special attention has been given to disaster risk reduction while implementing PDR. Selection of land, free from natural hazards was a challenging activity identified in all three cases mainly due to scarcity of such lands. Red Cross (2010) revealed that an emerging issue with this land selection is that the focus is given to providing a safe place from a certain hazard, resulting in exposing communities to new unexpected hazards. With the awareness of the aforementioned challenges, authorities were keen to build up the houses with disaster resilient features considering the most possible disasters of the particular area. Building up hazard resistant structures is a main feature of the BBB concept to minimize damage from future hazards. The most appreciative fact is that authorities have managed to include these features in owner-driven projects as similar to donor driven-projects strategically. For instance, while the authority designed the project with resilient features in Case 1, in both Case 2 and Case 3, having specified disaster resilient features was compulsory for the approval of design. Thus, community had no choice but to incorporate those features even they are dissatisfied with resilient features due to unawareness.

Community in Case 2 and Case 3 which were owner-driven projects, had a strong feeling that integrating disaster resilient features is a useless effort which associates an additional cost. This suggests that the community who is considered as the constructors were not aware enough about the importance of disaster risk reduction and the resilient techniques which need to be cleared out in future projects.

Moreover, allowing the community to select their own disaster free land in Case 3 was more successful as it considered community expectations. In fact, community participation is a successful procedure to apply in PDR projects, after educating them about the importance of disaster risk reduction and BBB concept.

5.2 Community Recovery

In BBB concept community recovery is discussed in two aspects; economic and social. Federal Emergency Management Agency (2011) had suggested BBB concept has the major concern to create opportunities for social and economic development of communities through PDR projects. Common problem of most of the beneficiaries in all three case studies was losing their livelihoods due to relocation. Most of them have complained about the difficulties of travelling to their previous workplaces from the new location while some of them have lost their cultivation in their previous places. The findings suggest that authorities have not given consideration to the occupations of community while selecting the lands. Moreover, no coordinated process was introduced to provide alternative jobs for the people to recover back to their normal lifestyle. For instance, in Case 2, the community were given support for cultivation which is useless due to having insufficient space.

Communities were recovered socially in Case 1 and 2 by improving common facilities of the residents. According to 'house for a house' concept of government every family had an opportunity to own or to construct new houses with more facilities. Moreover, the government has provided social gathering places to encourage social recovery. However, their productivity was not at an adequate level because community didn't pay much attention to them. This may be because there were much more necessities in people's lives to get recovered than social gatherings.

The findings suggested that in many instances the authorities have failed to provide maximum facilities while selecting the land such as public transportation and schools to facilitate day to day activities of the community. The authors suggest that these concerns may be neglected mainly due to the time and cost constraints of PDR projects which can't be avoided. However, there were some successful projects in this regard like Case 2 which was embraced by the community.

Some of the community recovery practices identified from Victoria bushfire recovery such as involvement of community in implementing recovery projects, promoting owner-driven reconstruction with enough support, rebuilding public facilities like community halls (Mannakkara and Wilkinson 2015) were implemented in Sri Lankan PDR projects too. However, community recovery is not achieved up to the expected level as mentioned in the literature survey. All these cases are mainly funded by the Sri Lankan government which had resulted in insufficient funding for community recovery activities.

5.3 Implementation

Government has an implementation framework prepared by NBRO to carry out PDR works. In this implementation framework responsibilities of all the stakeholders were clearly identified at each stage of reconstruction project. Accordingly, having a proper guideline for implementation of PDR activities can be identified as a good practice of BBB in PDR. NBRO had published guidelines to inform beneficiaries and authorities about implementation of PDR programme. Beneficiaries had to follow the implementation guideline to receive the funds from the government for their reconstruction activities.

In PDR projects, two types of housing reconstructions were carried out as Owner Driven and Donor assistant [17]. Case 1 is a donor assistant reconstruction project

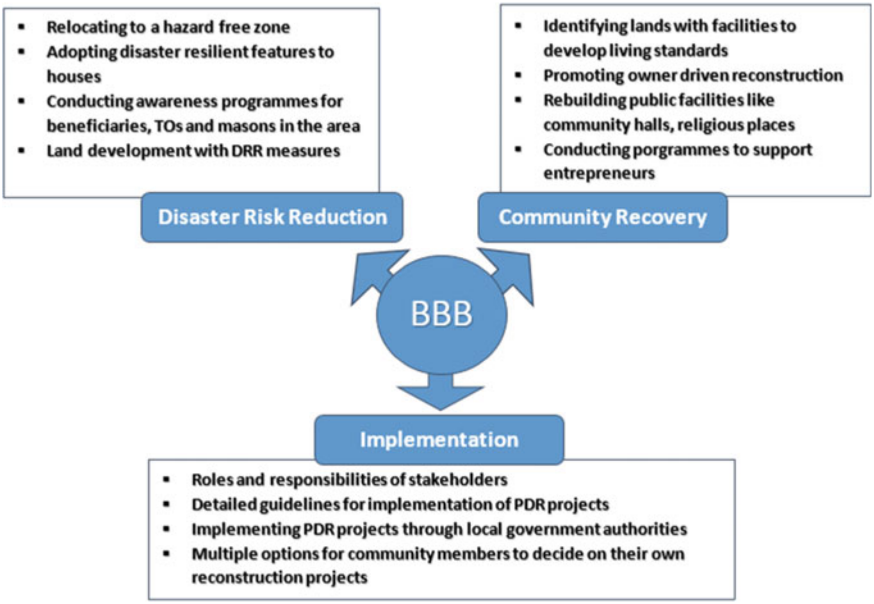

Fig. 2 BBB practices in Sri Lanka

while both Case 2 and Case 3 are owner-driven projects. Therefore, Case 2 and Case 3 had allowed more community participation in reconstruction activities which was appreciated by the community. Options given to the beneficiaries in the above-mentioned guideline had allowed them to make decisions considering their own social and cultural expectations.

According to the empirical findings of the case studies, local government authorities and NBRO work together in implementing PDR projects. Therefore, necessity of a separate authority or organization has not occurred during the implementation of PDR projects.

The above findings on BBB practices related to key areas of BBB are illustrated in the following Fig. 2.

6 Conclusions

This research signifies the implementation of Build Back Better (BBB) concept in Post-Disaster Reconstruction (PDR) projects in Sri Lanka. BBB concept was introduced to Sri Lanka after the Tsunami 2004. BBB aims to enhance the effectiveness of disaster recovery activities in future disasters expressing the best practices that stakeholders should follow in the recovery stage after a disaster. Disaster Risk Reduction, community recovery and implementation are three key components of BBB that were identified after reviewing the concept. However, there was a necessity to identify the practices of BBB used in Sri Lankan context in order to assess the success of BBB implementation. Hence, the study was carried out to investigate the BBB practices and their issues while implementing them in Sri Lanka. The study was focused on landslide and flood PDR projects conducted since they are the most common disasters that occurred in Sri Lanka.

Accordingly, many BBB practices were identified under three key areas of BBB which resulted in both successful and unsuccessful outcomes. However, the disaster affected community did not see any importance of BBB to improve their lifestyles. They believed that their lives before disasters were better compared to new lifestyles in PDR projects. Majority of the community had lost their properties and livelihoods due to disasters. Affected communities argued that the value of lost properties and lives during disasters cannot be replaced by any concept. However, some of them agreed that building houses with resilient features reduces the risk of experiencing another disaster in the future. It was a relief to them as they had lived with the fear of disasters in the previous location due to risk.

According to research findings, implementing BBB practices identified in this research helped to overcome some challenges in PDR such as minimizing corruption, non-availability of labours and materials and funding issues. However, proper practising of implementation guidelines that have been designed based upon BBB is required to attain successful PDR. Even though good practices have been identified in Sri Lankan context, neglecting responsibilities of stakeholders has become the barrier to assuring the achievements of BBB in PDR.

According to research findings, BBB is a concept of reconstruction that can be adopted for the development of PDR in Sri Lanka. This concept plays a major role in creating disaster resilient communities in the world. Thus, BBB is not a concept limited to improving disaster resilience. The concept of BBB is to improve the state of affected communities to a less vulnerable state prior to a forthcoming disaster. After a disaster, lifestyles of communities are greatly changed. Therefore, PDR activities must support people to adapt to changes in a better way. Community recovery practices identified in BBB concept help to develop social and economic conditions of a community.

Accordingly, implementation of BBB in PDR activities can be recommended for the development of the community in Sri Lanka. Using funds for implementation of BBB can be considered as an investment for development in the country which should be considered by the Sri Lankan government. Sustainability of reconstructions is another achievement of BBB as it reduces the risk of disasters.

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Disaster Affected People's Vulnerability Assessment Through Addressing Padma River Bank Erosion

Md. Awual Baksh, Sharmin Akter, Md. Shahidullah Pramanik, and Farzana Bobi

Abstract Rajshahi, a divisional city of Bangladesh, is located on the bank of the Padma River. Peoples living in the riverbank areas face different types of natural hazards like floods, riverbank erosion, and draught. For the immediate years, riverbank erosion causes severe damages to the Char people who lived beside the city. So, this study focuses on identifying the erosion affected peoples' vulnerability during flood and riverbank erosion. Both qualitative and quantitative methods were followed during the study. To identify the vulnerable condition of the people's several variables like damages of the resources, economic crisis, unemployment problem, food crisis, various diseases, and social problems were measured. The results show that riverbank erosion causes huge losses of land, houses, crops, and other assets of the residents every year. Besides they suffer from a short time severe food crisis, diseases, and unemployment problems as well. They get only a limited amount of help from the government and non-governmental organizations. They mainly get helps from relatives and kin-members. It is supposed government assistance does not often reach the vulnerable and affected groups due to the insincerity and dishonesty of the responsible authorities. As a result, during the disaster, they resettled themselves in the city either on the embankment or here and there. They also face various problems and City Corporation also failed to handle the problem properly. So, the researcher suggests some specific actions to prevent the rapid river erosion incident along with some other recommendations to reduce the vulnerability of the affected peoples.

Keywords Riverbank erosion · Vulnerability reduction · Adaptation · Qualitative and quantitative research

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1 Introduction

1.1 Background of the Study

Riverbank erosion is an environmental calamity in Bangladesh that is more frequent and devastating in comparison with other kinds of natural inversion in Bangladesh. Day by day environmental refugees are increasing due to riverbank erosion at the riverside areas of Bangladesh [13]. Some of the researchers claim that climate change, geographic location, and geomorphologic conditions are more likely responsible for the increasing number of riverbank erosion events [25]. Millions of affected peoples lost their croplands, homesteads, farmlands, and more other valuable things due to riverbank erosion. And the most alarming issue is that around 5 of total floodplains is directly affected by riverbank erosion in Bangladesh. The situation mostly goes worsens during the monsoon season because of gradual migration of channel shifting of the river and high volume of water with a higher flow rate. Unpredictable shifting behavior not only affects the floodplain populations but also cause great damage to urban infrastructure and hampers urban growth [4, 12, 17]

In Bangladesh, different types of impact of riverbank erosion can be seen among the affected peoples. Some of the major impacts are social, economic, environmental, political, and health impacts [19]. Resulted multidimensional problems also create many problems for the affected peoples with the changing economic, sociopolitical, cultural adaptation strategies and that happens at the selected study area of this study.

To solve the raised problems regarding the adaptation strategies of the affected peoples at first, we must know the context and aspect of the vulnerability of any area. But, there is always lacking proper study and initiative to explore the extent and context of the vulnerability of the affected area and community. Even the aspect of adaptation strategies and mechanisms to survive in society is always remain unknown to us. And the reason behind this is being at the "*Char*" (Tracks of land surrounded by water) area that is located at far away from the city area. So, this research was conducted on one of the wards of Rajshahi City Corporation (RCC, Ward-29). Based on the field study, this research identified different types of vulnerability in the study area (Fig. 1).

1.2 Objectives of the Study

The goal of the study is to analyze the vulnerable situation and take different kinds of adaptation strategies for the river erosion affected people in the Dharampur community (RCC, Ward-29) during the erosion and post erosion period. The specific objectives are below:

- To find out the nature of the vulnerability of erosion affected citizens in the study area.

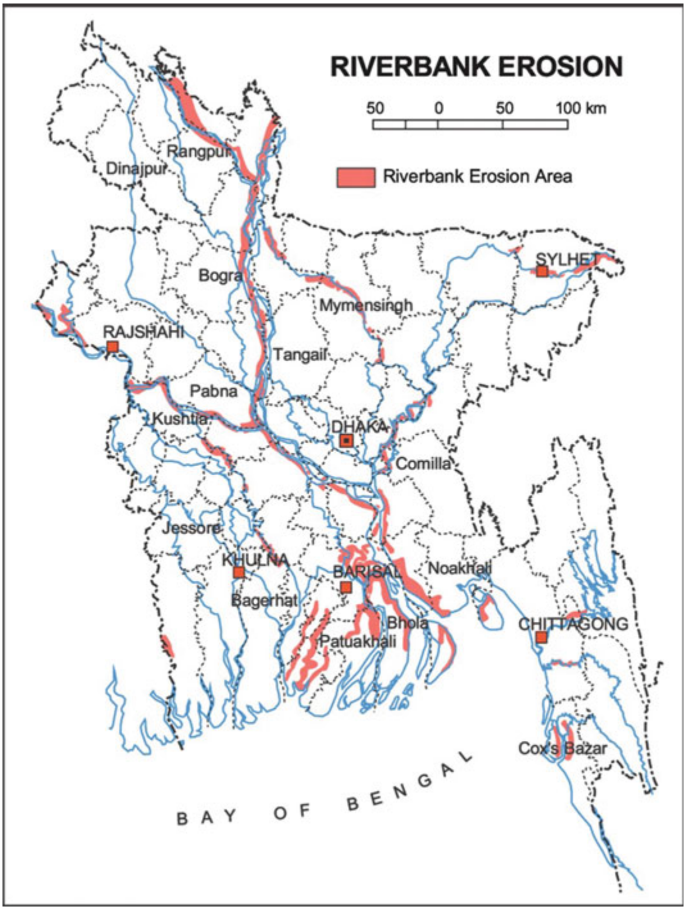


Fig. 1 Vulnerable areas of river bank erosion in Bangladesh

- To examine the impact of erosion on the livelihood and social aspects of the affected people.

2 Literature Review

Bangladesh is known as the land of rivers and about 230 rivers across the country. Most of the cities are located beside the river. Thus, the effect of riverbank erosion on the city is very much. Every year erosion affected people who gathered or resettled themselves into the city during the time of flood and post-flood period. Table 1 will show the riverbank erosion affected cities of Bangladesh:

Table 1 The riverbank erosion scenario of Bangladesh

S. No	River	No. of breaking points	Breaking area (m)	Affected cities
1	BrahmaputaraJamuna	43	162,544	Sirajganj, Kurigram, Jamalpur, Gaibandha
2	Ganges-Padma	26	94,433	Rajshahi (Godagari, Sardah, Nobinagara, Bulanpur)
3	Meghna	8	67,044	Chandpur
4	Teesta	8	34,854	Rangpur
7	Surma	23	13,224	Sylhet
8	Kushiara	17	11,003	Sunamganj, Jakirganj, Fenchuganj, Sherpur

Source Islam, 1985

Rajshahi is an old city and situated on the bank of the Padma River. Bangladesh Water Development Board (BWDB) was started a project named “Rajshahi City Protection Project” to protect Rajshahi City from the flood and erosion created by the Padma River. This project is mainly focused on flood control, drainage, and protects the city from river erosion. The duration of this project was 3 years (from 2004 to 2006). Under this project, 17 km river bank protects the wall, 19 regulatory sluices, 7 groins, and 1 spar were constructed. This project demarcated 1715 hectares of the drainage area and 6868 hectares of flood control area (Source: BWDB).

Vulnerability accesses the socio-economic and environmental conditions. These include the location of homes, structure and type of housing workplaces. And both of these are strongly related to different types of factors like household income, availability or cost of building materials, legal and social limitations on land use and the location and variety of livelihood activates. In the years 1988 and 1998, in Bangladesh, two subversive floods took place. During these floods, more than 65 of the country’s geographic area got inundated. The impacts of those floods and riverbank erosion on society and economies were so severe that it took a longer time duration to back the affected people at a normal life and to minimize the losses. An analysis of crop damage to wet seasons shows that annually 3.7 of crop production often gets at damage-prone annually (averaged over 37 years).

In the case of vulnerability assessment, The Inter-governmental Panel on Climate Change [7] presented vulnerability as a function that considers the character, climate variation rate, magnitude toward which a system is exposed. Vulnerability also includes both internal and external dimensions like exposer to climate (external), sensitivity, adaptive capacity (internal) [10]. Some researchers also focused on realizing both biophysical and socioeconomic processes simultaneously [2].

Disruptions of communication and losing of crops reduce the availability of food, which results in an increasing food crisis and increases the price of local foods. The resulted situation creates a hardship for the poor in terms of food availability and provisions. To solve the raised problems in case of any disaster, a sustainable adaptation strategy is must require. Adaptation strategies for climate change include different types of adaptation strategies at the socioeconomic system, transportation system, and environmental systems as well. But in the case of developing countries like Bangladesh, most of the time context of vulnerability often exceeds the capacity of the community or countries. And so, the goal of the adaptation strategies must be increasing the capacity along with reducing the extent of vulnerability.

As a most efficient way of assessing system current adaptation strategies for disaster management, the IPCC technical guidelines proposed a process, "seven steps adaptation development strategy" [6]. The steps pointed to some specific issues like defining the objectives, specifying the important climatic impacts, identifying adaptation strategies, revealing constraints and examining alternative strategies, evaluating tradeoffs, and recommending some other adaptation measures [6]. Historically, women and men in natural disasters like drought, flood, and riverbank erosion have evolved their strategies, coping mechanisms to protect their assets, to increase livelihood security, to protect their families. In most cases, these methods are no scientific and these are experience-based strategies. Some of these are preserving dry foods so that they can support their families during the flood. Some of them preserve seeds for post-flood cultivation processes [16, 29].

As the main cause of riverbank erosion is flooding, the idea of controlling floods and minimizing the losses started after the devastating floods that took place in 1954 and 1955. Bangladesh Water Development Board (BWDB) was formed as the first legal institution to control floods, making embankment, incentives to minimize the losses of life and assets, and post-flood activities that is the current flood management planning and executing committee. After the flood in 1954 and 1955, another devastating flood of 1988 and 1998 took place. After that, flood action plan (FAP) and a series of mitigation plans and programs are taken [27].

Vulnerability and loss of property of riverside slum areas are common at riverbank erosion. To overcome these problems, national level institutional arrangement, safeguard policy statement (SPS), income and livelihood restoration program (ILRP), resettlement program have already taken [5]. But, in the study area there has a weak evidence of proper implication of these rules.

Although different types of plan and policies have already taken by BWDB, Char areas in Rashahi specially Dharampur and Char Khidirpur areas face devastating riverbank erosion in almost every year. The amount of property and other thing losses is also significant. A study on riverbank erosion on Gaibandha and Sirajganj district by Unnayan Onneshan, (2012) showed that, along with socio-economic loss and property damage, affected people faces different types of health issues. And the displacement causes a great experience to the affected peoples. But, it is a matter of concern that still now a little or no number of studies are available regarding riverbank erosion at the selected study area. In case of the selected study area, as the area is far away from the city corporation area, and basically a char area, so the area always lacks of adequate research and attention of the city authority.

3 Background of the Study Area

Dharampur community is selected in this study area, which is situated in Rajshahi City Corporation. The area was selected as the study area after systematic field reconnaissance, verbal interview survey, expert opinion survey, and key informant survey. The total area is about 3.5 square km. The population size of this community is 3500. Another 1500 people came here to resettle themselves after riverbank erosion which vanishes everything from their village named “Char Khidirpur”. The Padma River is across between Dharampur and Char Khidirpur. For the geographical location, flood occurs here every year. The duration of flood is generally 15 days to two months from last August to mid of October. The causes of floods are heavy rainfall and the Farakka barrage. There is only one embankment (Rajshahi City Protection Embankment) which is located beside the city, while the other side of the river has no embankment. As a result, riverbank erosion highly affects the embankment during and post-flood period. During the time of flood and post-flood period, the affected people made their alternate shelter in Dharampur. Most of them were built their houses on the embankment. Housing pattern: Most of the houses are made of tin, hay, and bamboo; some houses are made of brick, but the roof is made of tin. Most of the affected people losing their job become unemployed. They become day labor to feed themselves and their family. Dharampur area has the local market for marketing necessary materials, primary and high school, Madrasha, and five Jumma Mosques. Though the area is located in the city, all the facilities do not reach the resettled people. The GO and NGO activities are not enough for the erosion affected people (Fig. 2).

4 Methodology

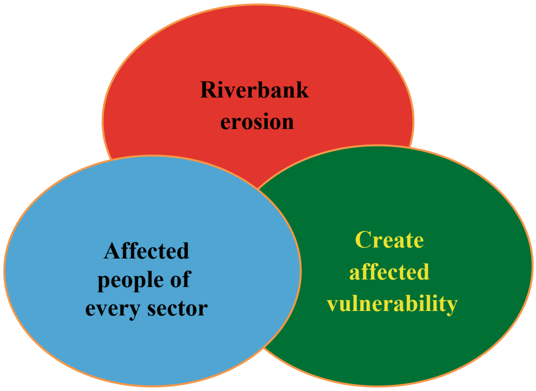
In this study, a mixed-method research approach was adopted. The approach utilizes both qualitative and quantitative research methods. For a quantitative approach, a self-developed questionnaire survey was used for data collection. About 301 people have been selected for the questionnaire survey. The respondents of the Dharampur community (RCC, W-29) were selected by random sampling. All respondents were selected from sex, religion, and no discretion was used in collecting information from the respondents. For the qualitative method, a verbal interview, key informant survey were used. So, all of the necessary data and information were collected from primary and secondary sources. The structured questionnaire survey is used to clearly understand the following issues:

Fig. 2 Rajshahi district and city corporation area**.** The satellite view of the study area (Dharampur, RCC, W-29)

- Vincible people's socio-economic and socio-demographic status.
- Flood and riverbank erosion rapidity.
- Economic loss causes due to riverbank erosion.
- Human responses to riverbank erosion behavior.
- Social capital status after resettlement in the city.
- Issues of adaptation and vulnerability imposition.
- Policy intervention toward vulnerability, and adaptation.

This study is more concerned with people's vulnerability and human reaction to hazard (how affected people adapt to riverbank erosion) rather than the physical disposition of erosion. In this sense, this study has adopted "multi-method" research techniques.

In this research, data collected through a structured questionnaire survey by random sampling and has been analyzed in terms of the frequency distribution. Besides, necessary graphical representations have been used to represent data. These activities have been conducted by using SPSS and MS Excel used for some cases. The other qualitative data gathered from case studies are analyzed by hand and those have been represented in descriptive mode. For qualitative data, observed phenomena were also emphasized with the collected questionnaire survey data, verbal interview, and key informant survey data.



5 Data Analysis and Result

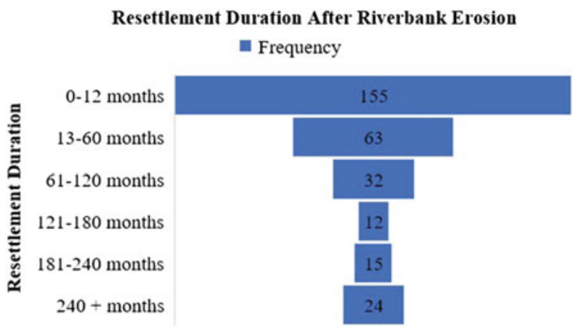
In this study, each respondent was considered as a unit of analysis. The representative of the household (HH) has been preferred to interview while judge as a respondent. A total of 301 households were interviewed where 38.9 male and 61.1 female respondents. In the beginning, demographic and socioeconomic information had been collected from each respondent including their age, sex, gender, education level, occupation, and so on. This information provided facts that helped the researcher to reach the point.

5.1 Effect on the Livelihood of the Respondents After Riverbank Erosion

Flood and riverbank erosion brought to the riverine people a lot of problems. They are highly affected by this natural phenomenon more or less annually. Every year they lost their house, habitat, crops, agricultural land, pet animals, and trees. Also, they face to change their regular work, and they have to divert themselves to other professions which they didn't want.

Duration of resettlement of the respondents after riverbank erosion. The duration of resettlement mainly depends on the severity of the disaster. The percentage distribution of respondent's resettlement duration after riverbank erosion. A large portion (51.5) of the total respondents is resettled in the city very recently due to seasonal flood and riverbank erosion as well as riverbed destruction, *i.e.,* 12 months ago. 20.9 of them have resettled themselves in the last five years. Along with the 8 of the respondents are living here for the last 20 years after their resettlement in the city (Fig. 3).

Fig. 3 Resettlement duration of the respondents



Major Losses/damages faced by the respondents after riverbank erosion. Apart from the damage and loss of dwelling, many other types of resources always face losses and damages due to riverbank erosion. Some of the common resource losses are crop damage, loss of land, animals, trees. All of the losses have a great impact on the changing livelihood pattern of the residents. Some of them decide to change their occupation. That is not all, the whole things create a great problem for the educational system of the area. From the analysis, it has been observed that 83.72 of the total respondents are lost their crops (either paddy or vegetable crops). About 99.67 of the total respondents are lost their habitat and dwellings; 98.01 lost their land; 83.72 lost their pet animals (including cattle, poultries) which were their secondary income source also. About 74.75 lost their trees, small vegetable gardens, etc. Occupational change occurs to 51.49 of the total respondents (Table 2).

Dwelling damage of the respondents by riverbank erosion. Dwelling loss and damage are one of the most common and severe losses of the affected peoples due to riverbank erosion. From the data collected from the respondents, it has been observed that about 52.8 of the total respondents are lost their dwelling due to flood and riverbank erosion, and 25.9 lost 2 times. 20.6 of them is lost for the first time, while 0.7 of the total respondents are lost their dwelling more than 3 times. So, the results show that the affected people rarely come back to the affected areas after they lose their dwellings twice at the riverbank erosion incidents.

Table 2 Distribution of problem/loss/damage faced by the respondents after riverbank erosion

	Crop loss (%)	Dwelling damage (%)	Land loss	Animal loss	Tree loss	Children's study problem	Occupational change
Yes	83.72	99.67	98.01	83.72	74.75	85.05	51.49
No	16.28	0.33	1.99	16.28	25.25	14.95	48.51
	100	100	100	100	100	100	100

Source Field Survey

Housing loss of the respondents by riverbank erosion. Previously, we have found the number of people who lost their dwelling and also found the frequency of losing their houses. In this section, what number of houses they frequently loss was found. Around 71.4 of the total respondents lost 1–3 houses, while 28.2 lost their 4–7 houses, and only 0.3 of respondents lost more than 8 houses by riverbank erosion. So, the majority of the affected people losses 1–3 houses frequently.

Losses of cattle's and poultry of the respondents by riverbank erosion. The livelihood of the peoples in the Char area mainly depends on agricultural activities, having cattle's and poultries, small scale business activities. So, the loss of these activities means a great loss toward their livelihood sustainability (Figs. 4 and 5).

In case of loss of cattle's, 59.8 of the total respondents lost 1–5 cattle, while 8.3 lost their 6–10 cattle, and only 0.3 of respondents lost more than 15 cattle by riverbank erosion. About 30.6 of respondents didn't have any cattle during the disaster period. In the case of loss of poultry, about 40.2 of the total respondents lost 1 to 10 poultry, while 12.3 lost 11–20 p, and only 0.3 of respondents lost more than 50 poultry by riverbank erosion. About 46.2 of respondents didn't have any poultry during the disaster period.

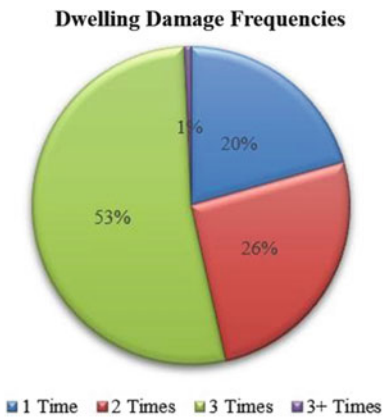


Fig. 4 Parentages of dwelling damage of the respondents

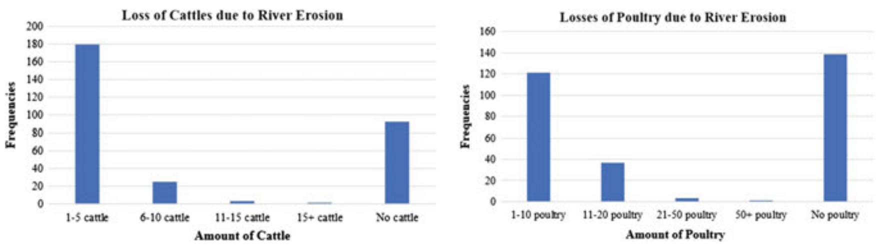


Fig. 5 Loss of cattle's and poultry due to riverbank erosion

Table 3 Percentage distribution of pre-and post-riverbank erosion land status of the respondents

Land area (in decimal unit)	Agriculture		Non-agricultural		Dwelling ground	
	Pre (%)	Post (%)	Pre (%)	Post (%)	Pre (%)	Post (%)
0	10.29	89.04	79.4	97.01	5.32	23.92
1–99	32.23	5.98	19.27	2.99	93.69	76.08
100–330	43.85	4.65	1.33	0	0.99	0
331–660	10.96	0.33	0	0	0	0
661–1650	2.67	0	0	0	0	0

Source Field Survey

Distribution of other losses of the respondents by riverbank erosion ***Loss of trees***. About 36.2 of the total respondents lost 1–5 trees, while 10.3 lost 6–10 trees, and only 0.3 of respondents lost more than 20 trees by riverbank erosion. About 46.2 of respondents didn't have lost any tree during the disaster period.

Loss of ponds: From the interview, it has been noticed that the percentage of pond damage is null, *i.e.,* any of the respondents haven't pond. They were fishing from the river directly.

Loss of Boats: About 85.4 of respondents didn't have any boat during the disaster period, while 14.3 of the respondents had 1 boat which they sold after riverbank erosion to overcome some of their misery.

Loss of Business: Only 0.66 of the total respondents had other small businesses as their secondary income source which damage at the period of river erosion.

5.2 Before and After Riverbank Erosion Land Status

After flood and riverbank erosion, most of the respondents lost their habitat and agricultural and non-agricultural lands. About 89.04 of the total respondents lost their cultivable land, 97.01 lost their non-cultivable land, and 23.92 lost their dwelling ground. Only respondents (10.96) have land for cultivation. Moreover, a huge change in the land status at agricultural, non-agricultural, and dwelling change has occurred due to the erosion (Table 3).

5.3 Before and After Riverbank Erosion Dwelling Status

About 14.3 of respondents were lost their house. 79.1 have smaller and only 6.6 has a larger house than the pre-riverbank erosion period. After riverbank erosion, 14.62 of total respondents lost their house, while all the respondents have their own

Table 4 Percentage distribution of pre-and post-riverbank erosion effect on the dwelling structure

	Wall			Floor			Roof	
	Pre (%)	Post (%)		Pre (%)	Post (%)		Pre (%)	Post (%)
No house	0.00	14.62	No house	0.00	14.62	No house	0.00	14.62
Bamboo	86.05	63.46	Katcha	99.67	81.72	Bamboo	68.77	30.56
Tin shed	1.66	7.31	Semi-pucca	0.33	1.99	Tin shed	31.23	54.15
Mud wall	12.29	14.61	Pucca	0.00	1.66	Pucca	0.00	0.67

Source Field Survey

house before erosion. The rest of the respondents built their houses after resettlement. Table 4 shows that after resettlement the respondents built their house with better equipment. The percentage of using tin very much increased in all cases. A very low percentage of respondents (about 0.67) made their roofs with concrete.

5.4 Occupational Change After Riverbank Erosion

A significant amount of occupational change occurs among the respondents after flood and riverbank erosion. After losing the cultivable land about 15.9 of farmers lost their profession, and they chose the alternate profession. So, the percentage of day labor, a rickshaw puller, and unemployed increased. Before riverbank erosion and flood, major occupations among the respondents were farmer, homemaker, and day labor. After flood and riverbank erosion, people mainly switched to small businesses, day labor, three-wheeler/van driver etc. Besides, the unemployment situation among the respondents increased from 1.7 to 4 (Fig. 6).

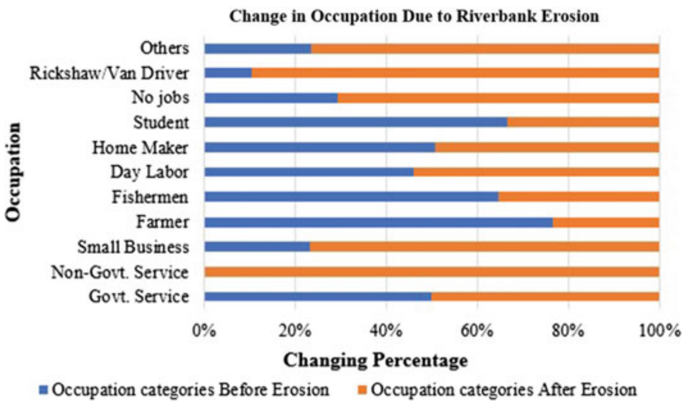


Fig. 6 Occupation change due to riverbank erosion

5.5 Resettlement Problems After Riverbank Erosion

The riverine people not only faced problems during the time of flood and riverbank erosion it continues for many years after resettlement. They become a victim of various resettlement problems in the city after riverbank erosion. Among these, first of all is the place of alternative shelter of the respondents in the city. Most of the people haven't relatives or own house so they have to resettle themselves either on the river embankment or in the disaster shelter after riverbank erosion. In this case, most of the respondents (76.4) resettle into their own home, 14.3 to another house, and 6.6 to relative's house; 2 resettle themselves on the embankment of the river.

Pre- and post-erosion drinking water sources and sanitation status of the respondents. During the flood and riverbank erosion, problems with drinking water and sanitation facilities increase at a rapid rate. At a normal time, people mainly use tube well and river water for drinking, taking bath, and other purposes. But, most of the respondents (95.7) drink tube-well water after riverbank erosion for safety purposes. In some cases, they also use community water supply tap (3) for getting pure drinking water. In the case of sanitation facilities, around 85 of the respondents get the facilities of using Pucca toilets after riverbank erosion. After that, around 8 of the respondents get the facilities of using semi-Pucca toilets. The rest of the respondents (7) use the Katcha toilet as well.

The situation of other basic facilities. About 83 of the total respondents confirmed the waste management problem. About 61.5 of respondents haven't the electricity supply facilities due to their inability. About 87.4 of the total respondents confirmed the health service problem. People also face communication problems due to riverbank erosion. In the study area, 65.1 is covered by pitch road followed by herring-bone bond (HBB) road 20.9 and 14 soil road (Fig. 7).

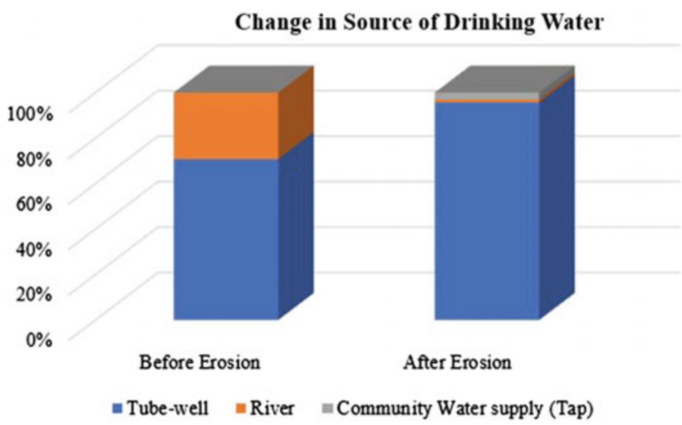


Fig. 7 Change in source of drinking water of the respondents

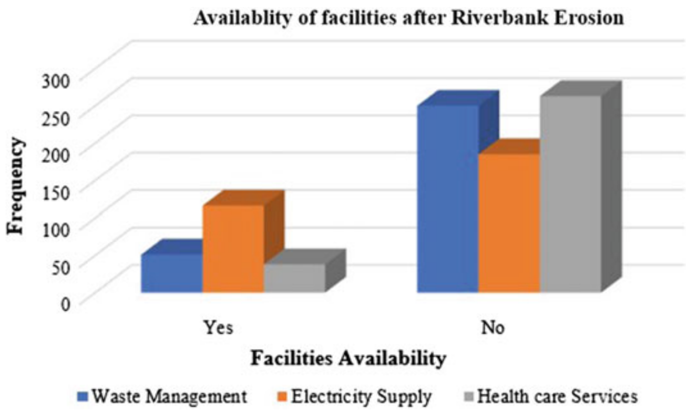


Fig. 8 Facilities availability after Riverbank Erosion

Educational institution. A positive response to educational opportunities to the respondent, in this case, has been shown. The area has schools, Madrasah, colleges, and universities. So, the respondents have a better chance to educate their children than the pre-riverbank erosion period (Fig. 8).

5.6 *Social Capital Status in the City After Riverbank Erosion*

Natural disaster(s) caused heavy damage to the victim people both financially, mentally, and socially. First of all, victims lost their habitat, financial way of living. Secondly, they are depressed and deprived mentally, and lastly, they are detached from their previous relatives/neighbors. In the meantime, they also face poverty due to insufficient aids which are reflected in their economic and social deprivation and their vulnerability to different types of crisis events.

Communication and social behavior with the other relatives/neighbors. About 82.4 of the total respondents communicate to their relatives after riverbank erosion, while the rest 17.6 of the respondents didn't communicate. The reason behind this is resettlement. They resettled in different places in the city area, so they are unable to contact each other at the regular interval after the flood and riverbank erosion period. About 95.3 of the total respondents have a good relationship with their new neighbor(s). According to the respondent's social behavior of the new neighbor(s) with the riverbank erosion affected people after resettlement in the city was good (78.1), and 6 was very well behaved with them, while 15.9 said that they were not effortlessly welcome by their new neighbor(s). Facilitate commitment of the new neighbor(s) to the resettled people is just over 50 (51.8) which indicates that the affected people have faced various problems during the time of resettlement in the city (Fig. 9).

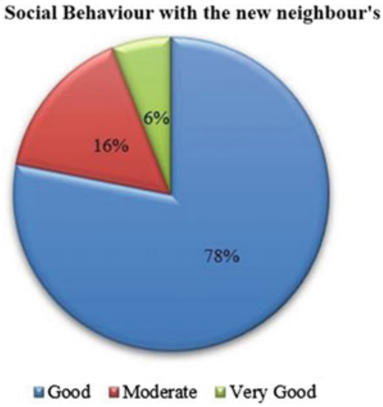


Fig. 9 Neighborhoods behavior at resettled areas

Environmental safety and women's safety after resettlement. After resettlement, one of the major issues of concern is the safety and security at the resettled area. 75.7 of respondents state that their women are secured in the city after resettlement. About 79.4 of the total respondents have concurred that the city environment is better than their "char" environment.

Job opportunity in the city area. About 79.4 of the total respondents have concurred that they had better job opportunities than their "char" environment. Due to the lack of adequate job opportunities, some of the resettled people often allied with the illegal job(s) after resettlement in the city, while they were not associated with these before resettlement. The reasons behind this are their poverty, insufficient job opportunities, low income, and inadequate aids from different organizations to overcome the crisis conditions they had.

5.7 *Aid from Different Organization After Riverbank Erosion*

About 3.32 of the total respondents obtained government aids and only 0.99 obtained aids from different NGOs, while no aids from the local or other side have been reported. As they didn't get any type of help or support from the GO or NGO, they have to sell their cattle and household utensils, ornaments to manage their livelihood in the critical situation of flood and riverbank erosion. Sometimes they took a loan from the "Local Somitee" or the NGO or the bank with the burden of high interest which also cause misery to them. According to the statement of respondents, about 15.94 of the total respondents took a loan from the Somitee and 3.65 from the bank) (Table 5).

Table 5 Aids/supports from different organizations to the respondents after resettlement in the city

Help status	Government		Local		NGO		Somitee		Bank loan		Other	
	Freq.	%	Freq.	%	Freq.	%	Freq.	%	Freq.	%	Freq.	%
Yes	10	3.32	0	0	3	0.99	48	15.94	11	3.65	0	0
No	291	96.68	301	100	298	99.01	253	84.05	290	96.34	301	100
Total	301	100	301	100	301	100	301	100	301	100	301	100

Source Field Survey

6 Recommendation and Conclusion

Based on our preceding evidence, it is reflected from our survey data that most of the villagers belong to the agricultural community, and severe riverbank erosion has already dislocated from the original settlement of this community. Being displaced, the respondents have taken accommodation in the new place, *i.e.,* Dharampur. They adopted traditional techniques for their survival during the serious situation of riverbank erosion. While exploring a brief history of the study area, a clear view of the local adaptation strategies was found. During and after a disaster or at the time of resettlement, the villagers mainly get help from the relatives and kin-members.

Whenever they come back to their previous residence, also then they get help from the relatives and kin-members for rebuilding and repairing their houses. During riverbank erosion, most of the villagers of the study area become fully shelter-less. And so, a quick response, recovery, and help are must require at that critical moment.

The study reveals that peoples having good savings can somehow manage the resettlement and food crisis dure the disaster, but poor peoples need social help and economic assistance to cope up with that situation. And sometimes they get helps only from relatives, they don’t get any help or assistance from the government or NGO’s in the emergency situation. Government assistance and NGO’s help either reach them quite later or not. For example, during interviews, we found that a few families received rice and clothes from government (3.32%) and NGOs (0.99%) but no aids from the local sector(s). The percentage of aids is quite insufficient for their survival. The scenario is quite the same for the local organizations and Ward Council. In that case, the villagers suspect that dishonesty and insincerity are the main reason that’s why government support does not often reach properly to them.

During the disaster, they resettled themselves in the city either on the embankment or here and there. So, that time population increased in the city. They also face various problems and City Corporation also failed to handle the problem properly. The goal of this research was to mitigate these problems and finding some solutions to overcome from riverbank erosion resettlement crisis in the city area. Several recommendations are suggested by the researcher to mitigate this riverbank erosion and resettlement problem in the city area.

6.1 Recommendation

This research has been conducted to focus on the socio-demographic, socio-economic, environmental conditions, and resettlement problems of the victims in the city after riverbank erosion.

To overcome these circumstances, the followings are recommended: Rehabilitate the embankment dwellers; giving priority to women and children who are the most vulnerable group.

- All of the governmental departments must have a clear idea and understanding regarding the impacts of climate change on their sector.
- The central government needs to decentralized development policy to plan for appropriate adaptation and mitigation strategies of disaster risk and vulnerability. National level activities need to be distributed to the local level. Provision of effective information along with different training and awareness-raising should take place.
- Only relief and aids cannot change the vulnerable situation of flood-affected people. The basic changes in socio-economic factors should be an effective strategy in removing vulnerabilities.
- Need to improve the transport communication system and an effective surveillance system.
- Sensitization/mass awareness-raising (for both public and policymakers) on natural disasters and management should be undertaken by both government and NGOs.
- The government should arrange seminars, symposiums to increase the participation of rural people in disaster issues and management.
- It needs to create a large scope of job opportunities based on confined planning to reduce vulnerabilities during flood and riverbank erosion.
- Awareness about the diseases during disaster time should be done on regular basis.
- New projects and policies should be developed to protect the infrastructures and permanent settlement for affected peoples.
- Construction of embankments using updated methods and technology to protect communities from the riverbank side to reduce the risks of erosion should be emphasized. Involving communities for routine management and maintenance of embankments will create a sense of ownership among the community peoples.
- Loan without or at very low interest from the government banks of Bangladesh should be provided to the disaster affected people.
- Local government needs to special care with the affected people during and post-disaster periods.
- Provide health and education facilities to the embankment dwellers. First-aid to the wounded and post-flood and riverbank erosion should be provided.
- Provide employment and increase the income-generating capacity of the women beside the men through training in skill development.

- Stop the threat of forcible eviction. Without proper measures of resettlement and rehabilitation, it will only increase human misery.
- The arrangement of alternate shelters for the affected people, possibly also for cattle and security of other properties should be built by the government.
- Community capacity building is very much solicited, and for this training should be arranged on disaster preparedness involving local government along with community people. This will enhance the capacity of the local community in risk mitigation and assessment.

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An Investigative Study on Material and Its Performance of Intermediate Disaster Relief Shelters

Divyatanu Dev and Shanta Pragyan Dash

Abstract Intermediate disaster relief shelters play a significant role after any disaster as it is an integral part of disaster response and recovery which helps to provide security and safety for the people who have left or lost their accommodation due to the disaster. These shelters not only provide accommodation but also help them to overcome the trauma of the disaster initiating the process of rehabilitation. In the past review of literature, case studies and reports related to the design of disaster relief shelters it has been found that due to the lack of adequate consideration related to climatic conditions, locally available materials, unskilled labour, cost constraints and other socio-cultural issues and construction delays resulted in its poor performance contributing to an unacceptable standard of living for the victims. The paper aims to explore the types of intermediate relief shelters with respect to various materials available through literature and case studies addressing the key factors affecting the environmental, economic, technical and socio-cultural criteria affecting the provision and performance of such shelters. The outcome of the paper is to propose strategic recommendations for addressing the major key aspects to be taken into consideration during the decision-making and design processes of such shelters for the effective and better performance of these shelters.

Keywords Intermediate disaster relief shelters · Decision-making · Design processes · Rehabilitation

1 Introduction

Disasters in any form continue to be devising recurring phenomena for the entire world [1]. The world disaster report of 2007 states that the number of disasters deported in the year 1997 to 2006 has increased drastically by 60% as compared during the phase 1987 to 1996 [2]. Since the Indian continent is highly vulnerable to

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disasters. Around 25 states of India are vulnerable to search for disasters. 56% of the total land area of the country is vulnerable to see snake activities [3]. Apart from the loss of life, the destruction of the house due to such disasters are the most important and critical concern after the disaster [4]. A disaster victim's shelter rehabilitation process is complex. The survivors' main challenge after the post-disaster is to meet the basic shelter needs of government and humanitarian agencies [5]. Disaster relief shelters are considered important for defence, security, climate control and resistance to disease and ill health. Such shelters are used mainly by people relocated from their original location and rehabilitated from permanent dwellings [6, 7]. Most examples of such shelters are plastic sheets, public community centres, places of worship, sporting venues, private rentals used as immediate shelters for disaster relief. Search filtering may be needed for a duration of several months or even years after the disaster [8]. Therefore, such shelters entail various planning and design aspects such as location, user needs and aspirations [9].

Some crucial concerns need to be addressed to achieve a successful outcome for the shelter needs of the victims of the disaster [10]. One of the main concerns is recognizing the shelter's specific need for the victims involved, what are the expected and actual time frame to fulfil their needs, what resources are accessible and are needed, the building process skills and local awareness and the degree of participation and influence of local communities during the construction process [3, 11]. Besides design, various NGOs, local authorities, politicians and volunteers who are the main stakeholders in the disaster process also need complementary support [12]. Although the facilities of such shelters are commonly accepted for immediate response and recovery from disasters such as earthquakes and tsunami, floods, it is not evident which shelter type is best suited under what circumstances in actual practice [13]. Because of this, many times such shelters prove ineffective in some cases hampered by unfit climate, local set-ups, costs, overcrowding and delays [14]. In addition to material visibility, local skilled labour is equally essential for building such shelters. In some cases, such rehabilitation shelters are of no value for potential storage and reuse [15].

In the paper's first phase, the authors address why intermediate disaster relief shelters are required during the disaster phase and what are the factors that influence these shelters performance during post-disaster scenarios. The second phase of the paper reviews the factors influencing the design decision of Disaster Shelters (environmental, economic, technical, socio-cultural) and investigates the different types of intermediate disaster relief shelters based on materials. The paper's last part suggests recommendations for consideration during the decision-making and design processes of disaster-resistant shelters for effective and better performance during disaster and post-disaster scenarios to increase their efficiency and performance.

1.1 Why is There a Need for Intermediate Semi-permanent Shelters?

Since disaster is natural or manmade in any form, it not only damages the dwellings of people but also has a severe impact on interacting aspects that shape human settlements such as human activities, the structure of socio-cultural and political-economic settlements, topography, geology and natural resources that define human settlement of a particular area [10]. To empower the victim during emergency rescue and relief, encouraging semi-permanent shelters is crucial to allowing them to engage in such collective processes to resolve the disaster's impact [11]. In this step, if the victim's shelter needs are properly addressed, the rehabilitation process of permanent dwellings can be enriched by integrating the above-mentioned factors [16]. Poor intermediate shelters typically trigger short-term settlement pressure [17]. It also needs a better understanding of the differences between emergency shelters immediately after the disaster and semi-permanent shelters in the first three months after the disaster, a crucial aspect of relief and recovery [18]. Emergency shelters usually provide immediate protection against heat, wind, rain, human life and the climate as simple shelters. Being a simplified view, but complex dynamics are observable over time [19]. Emergency shelters were found to be inadequate in terms of intermediate length before long-term construction of permanent houses as temporary relief [20]. Besides, there is less international aid funding and other programs to meet the tragedy-impacted people, relatively limited in numbers that do not resolve the immediate needs of the victims adequately [21]. In that case, immediately-motivated victims begin to create their emergency shelters with shared community support and their social network to overcome the disaster faster [22]. Often after a week, the group needs transfers to intermediate semi-permanent shelters allocated to families with inadequate and low-quality shelters [18, 23]. In the past, the victims gathered CGI boards, timber, etc. from the debris after the 1993 Marathwada earthquake to quickly create the shade for immediate use even before the government reacted in the form of organized relief shelters that came up later. Similarly, in Kutch Earthquake 2001, people have preferred building their immediate relief shelters on their clothes rather than heading to the tense black polypropylene sheets. The government's external response took over a week to reach the communities affected [24]. Likewise, in terms of their quality appropriateness and living conditions for victims, the inadequacies of temporary shelters after the 2004 Indian Ocean Tsunami were reported [10]. Therefore, considering all these considerations, it is necessary to note that the community victims themselves can manage immediate shelter response before organizations with piles of materials are reached. Along with this, understanding external humanitarian processes is necessary to focus on the immediate semi-permanent frameworks allowed by the community victims themselves.

2 Literature Review

2.1 Review of the Factors Influencing the Design Decision of Disaster Shelters

A comprehensive literature review of available documentation and research papers on Disaster Shelters was conducted to understand how these shelters were designed in the past to adapt to the types of disasters and with the disaster's environmental economic, technological and social context [15]. Transitional Shelter Guidance [18], Collective Centre Guidelines (Camp Co-ordination/Camp Management, 2010), describes the various types of shelters, where-as other guidelines are briefly identified in general papers such as "Strategic Planning for Post-Disaster Temporary Housing" [25] and "Guidelines to Improve Sustainability and Cultural Integration of Temporary Housing Units" [26], among others; others were written in government documents such as the Evacuation and Shelter Guidance [15], among others; and lastly, other guidelines can be taken from the Humanitarian Charter and the Minimum Standards in Humanitarian Response (The Sphere Project, 2011), among others [3, 2]. Factors relevant to the design such as the performance of shelters in consultation with the players concerned, government, private and other disaster recovery stakeholders, were summarized below in terms of addressing their environmental, economic, technical and socio-cultural needs.

I. **Environmental factors:**

a. ***Climate patterns*** are considered a critical factor influencing seasonal changes in possible disaster locations. People with different contexts and locations in different temperature regions will find different shelter types more suitable and comfortable based on their built environment [20]. Design elements such as high ceilings and verandas can cause shelters to cool down in hot weather, minimize air gaps, or provide a lobby area that can keep shelters warmer in cold weather [14]. Temporary and progressive shelters must be built to make the winter. Different climatic considerations require different shelter arrangements. Victims should have enough fuel and stoves in mattresses and beds in extremely cold temperatures, with sufficient clothes and blankets. Hot, dry and hot humid climatic ventilation plays an important part, as does the Sunshade [27]. In hot weather, a good drainage system is strongly recommended. The shelter should also consider potential temperature drops in open areas such as high altitude areas, deserts, etc. during the night.

b. ***Maintaining water and air hygiene*** is important to protect victims, personal and environmental hygiene. The shelter should address sufficient, often complex and expensive, sanitation, water supply and hygiene facilities [7]. Camp Co-ordination/Camp Management (2010), The Sphere Project (2011) has set standards for preserving health hygiene by introducing washing programs for people to wash their clothes and serve them with the best use of water for the disposal of human faeces, managing mosquitoes and diseases and maintaining a proper drainage system. Improving victim nutrition also finds appropriate storage facilities equally essential for treatment, hygiene and fitness [18].

c. ***Recycling, upgrading and disposal of disassembled shelter:*** As per International Mitigation Organizations 2012, disaster-resistant shelter material should be easy to recycle, reuse and relocate after the shelter is dismantled [28]. A shelter is described as recycled if it can be partially or fully replicated. However, if economic viability can be robust and appropriate in different climatic environments, it is environmentally friendly [15]. Therefore, it was highly advised that the shelters disaster consists of products recycled, upgraded and reused rather than disposed of after use [22]. Low-income families may also use these shelters as leisure camps or any other uses where permanent settlement is not desirable.

II. Economic factors:

a. ***Shelter types:*** The economic factor is a critical role in restoring and adapting to disasters [8]. Hence, shelter costs are often considered a significant element in ensuring affordable design [5]. The different materials used to build the shelters have already been addressed in the paper to be used for a temporary period [26]. The redesign and improvisation of the shelter are cheaper than moving face-to-face from temporary shelters to permanent constructions [18]. The practice of comparing the different types of shelters between host and affected populations is equally relevant in shelter design [14].

b. ***Durability and lifespan:*** Because designing and preparing disaster-resistant shelters with their expected lifespan and minimum quality and location requirements are equally relevant, the design process needs to consider its durability and the amount of money spent on it to maintain it for a long time [17]. In some cases, investing money in temporary shelters to permanent shelters is better to give them permanent residence if the contexts permit [28].

c. ***Victims' livelihood:*** In most situations where long-term relocation scenarios are apparent, victim assistance is required [29]. Help groups will help victims and locals make money by helping them start new business ventures after supplying the initial shelters [22]. For example, after the Great Eastern Japan earthquake, the victims started selling "Tamaki" or friendship bands made up of fishing nets along with some additional things like slippers, keychains, fabric back made by womenfolk. After such a catastrophe, it is important to raise the socio-economic status of the victims impacted by such activities to cope with the psychological rehabilitation of these victims [30].

III. Technical factors:

a. ***Ease of installation and dismantling:*** Selecting material for installation and dismantling is very important since it is lightweight and is available in modules [8]. If this design is complex, it may take more time and expertise to build it, resulting in potential delays [19]. A major feature of these shelters is that they can be rapidly built within a timeline to encourage fast recovery after a disaster [18].

b. ***Insulation properties:*** Any material chosen for disaster shelter should not only be inexpensive, locally accessible but should also avoid pollution of any kind without creating any harmful emissions, ideally it should be recyclable sustainable material to be easy to produce and create with its lightweight [31]. For example, prefabricated wood panels are flexible in size making horizontal and vertical transport simple and convenient with limited components. It was also decided that the shelter should be constructed with noise-insulating, weather-insulating and temperature-insulating materials to withstand the various climatic impacts and the built environment's surrounding effects [32].

c. ***Hazard performance:*** The shelter system should be built to protect its occupants from hazards including Storms earthquakes and other diseases. In such situations, structures made of bamboo framed ok timber are highly resistant to the fatality caused by the disaster by resisting the light structure compared to the masonry structures [2]. Contrary to this, areas are more vulnerable to extreme thunderstorms and high-speed winds. Therefore, it is important to have a system that takes into account areas vulnerable to flooding and high winds to withstand climatic pressure [21].

d. ***Psychological and physical effects:*** According to research, the victims who have lost their homes are experiencing serious stress issues [33]. Losing a house not only causes psychological stress, but also post-traumatic stress disorder that causes long-term detrimental effects on the survivor. Therefore, consumer attitudes and attitudes towards various types of shelters have often been important in terms of their effect on post-traumatic stress levels. Designers need to include develop features to reduce the stress effect of those impacted when constructing these disaster-resistant shelters [4].

IV. Socio-cultural factors:

a. ***Cultural differences:*** The shelter design has experienced a considerable difference, its orientation-style design element specifics among different countries, regions and even ethnic groups [17]. Therefore, it is important to adapt to local culture and community lifestyle to provide appropriate shelter solutions. It should represent the requirements and needs of users of traditional values family sizes, cultural practices, family, architectural styles religion and other relevant cultural aspects [18].

b. ***Security and dignity:*** Shelter design should not only be built based on a basic physical framework but should also make users feel socially integrated and provide them with space to live in a more dignified manner, taking into account security aspects [1]. The designs should recognize the integrity of privacy protection as well as the flexibility to promote the design so that users can change or alternate the design by inserting partitions in shelters according to the family sizes and specifications of the victim [4].

c. ***Social connectivity:*** In the early stages of disaster recovery, social interaction and communication are vital factors for the victims to be part of the recovery disease that happens during this time and to minimize the effect by allowing them to think about needs such as potential locations and needs

[32]. Communication should be improved in terms of social networks, television, radio, telephone, internet services, by organizing stakeholder training workshops [29].

2.2 Types of Intermediate Disaster Relief Shelters

a. ***Tarpaulin shelters:*** Tarpaulins tents procurement and distribution are the immediate first-phase disaster response initiatives (Fig. 1). Tents were always the commonly used relief shelters that were emergency shelters often found as a post-earthquake response in Western countries like Italy, Turkey, Mexico. They are not climate-friendly, however and offer limited security with very high costs. There are also many logistical challenges in vulnerable areas where tents with sufficient amounts are stored. Another major challenge is transporting these tents to areas affected by disasters. While these tents can be built in these areas, occupancy rates are very low as they are placed far from the victims' homestead plots.
b. ***Prefab concrete Shelters:*** Prefabricated shelters are another form of intermediate shelters available as the second choice during the disaster (Fig. 2). The selection of these shelters is based on the assumptions that they can be constructed and provided rapidly, as being a prototype would fit the families of the victims affected as it will be difficult for the communities affected to do so on their own voluntarily because of the disaster trauma. However, the rapid experience of these shelters indicates that there are very poor acceptability and efficiency in terms of climate consideration and functionality of the shelters, for example after the earthquake in Bam, Iran (2003), where these shelters were given but only a few people with smaller families moved into it as they preferred to remain only in their gardens and yards. Also, the distribution costs were very high compared to other relief shelters so people tend to build their permanent residence with indigenous materials in almost half the cost of the shelters as

Fig. 1 Tarpaulin shelter. *Source* Canvas relief shelter disaster tent

Fig. 2 Pre-fab concrete shelter. *Source* Emergency shelter design IN Habitat

seen in the Tsunami case in India despite the government spending around. $15 million per 10,000 interim shelters on Andaman Nicobar Islands for families affected.

These two types of shelters have not only failed to meet the standard donor requirements for the unit distribution and financial accounting but have also failed to represent the social-cultural and livelihood-related activities and needs of the victims' families. The rapid delivery and construction of these shelters were also considered. Rarely were distribution aspects considered because of complicated relations to the social structure of the household affected. This has contributed to the government and non-governmental organizations having increasing unrealistic expectations of the society impacted by a catastrophe that they have failed to meet. Owing to the exorbitant costs and the slow completion of such facilities during the pandemic, the result was adversely affected.

c. ***Steel Shelters:*** Steel as a Building material is being widely used because it withstands tension and is effective in dissipating earthquake tremors (Fig. 3). Steel elements can also be reused in the structural framework or formwork. But

Fig. 3 Steel shelter. *Source* Deep blue ningbo smart house

Fig. 4 Clay brick shelter. *Source* Alternative Africa, mass housing

the most challenging factor while using steel is its weight. The raw materials used for the manufacture of steel are again nonrenewable resources and also indulge a huge amount of labour for its construction. Along with this also the technical knowledge is required to join the elements without which the structure might tend to collapse. Post the Haiti Earthquake in 2010, simple Steel frames were provided as temporary shelter constructions which ensured protection, privacy and more space. Up to 2000, light Gauge Steel Shelters were built which were more resistant to hurricanes and heavy rains which have been designed to resist wind up to 120 to 240 miles per hour wind speed.

d. ***Clay bricks shelters:*** Clay bricks are another sustainable material that has been used for the construction of temporary Shelters in India during earthquakes. The material is easily available in and around the locality it is economic to procure the material for quick construction (Fig. 4). Since masonry is strong in compression but very weak in tension hence during the earthquake shake a significant number of deaths have occurred around the world because of this masonry houses construction. One of the major challenges of using this material is its drying process which takes a lot of energy and duration. During the post floods of August 2007 which hits the states of Uttar Pradesh and Bihar, small transitional houses incorporating brick plinths with a tiled bamboo roof were proposed which could have been more sturdy and safe than the kutcha houses made of thatch and mud.

e. ***Confined masonry shelters:*** Confined masonry is another type of earthquake material for construction during a disaster (Fig. 5). After the earthquake in Quetta in 1935, some innovations were made in the construction of Rehabilitation structures. Bricks are being good in compression but cannot withstand tension effectively whereas Steel as a material is good in tension. The bricks were laid in an interlocking pattern where the interlock gaps were filled with steel. This style of construction was adopted by the IIT Gandhinagar campus. The site is located in seismic zone III in compliance with the Indian seismic code. Student homes and staff quarters are suitable for the use of confined masonry technology

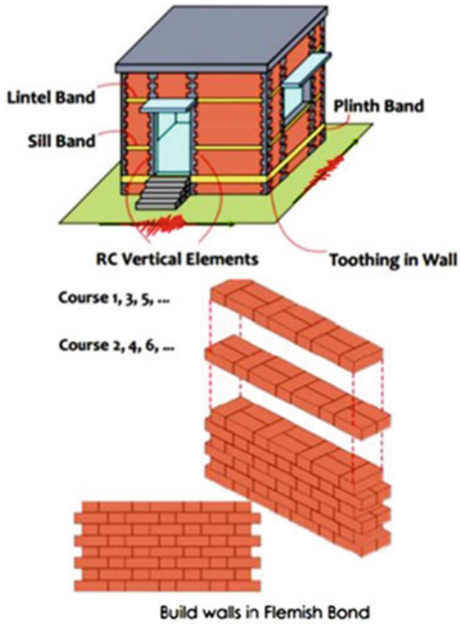

Fig. 5 Confined masonry shelter. *Source* Gujarat state disaster management authority

in buildings, small spaces (in contrast to academic facilities) and a large number of walls (wall density). Preliminary estimates suggested that the use of confined masonry technology would save 10 to 15% on alternative construction of RC frames.

f. ***Composite shipping pallets:*** Shipping crates used to transport items like fruits, vegetables, etc. may be used in shelter construction. Softwood, hardwood, plastic, cardboard, aluminium and composites are some of the materials that make pallets (Fig. 6). They are 100% reusable as shipping pallets and eco-friendly though easy to assemble and dismantle. The holes/gaps in these crates'

Fig. 6 Composite shipping pallets. *Source* In HABITAT

Fig. 7 Corten steel shipping containers. *Source* J K Technologies Private Limited

design help dissipate forces through it without letting it affect the structure. However, it cannot endure environmental conditions like rain or storm. This solution is only possible for earthquakes. This shelter cannot be used as a permanent shelter for material wood as it can attract insects. The holes/gaps in these crates' design can cause privacy issues. Originally built as temporary accommodation for Baltic War refugees in the 1990s, the accessible, robust shelter helps families to rebuild a house. Pallets of uniform size render it a perfect construction material. When supplies arrive from all over the world, shipping pallets can be erected to render partitions, ceilings and floors for those supplies. By coating these structures in local finishing materials, a quality shelter can be built that will last long enough for families to construct permanent housing.

g. ***Corten steel shipping containers:*** Recently, this material has seen its usage increasing due to its potential to be reused (Fig. 7). The material can be shipped and is weather resistant. Every unit houses up to four individuals, consists of recycled materials and can be assembled on-site with simple tools. And because units can be mounted on solid ground or float on six inflatable pontoons, they are extremely flexible for various circumstances. Shipping container units apply to a variety of impact areas, from a large-scale catastrophe involving high numbers of displaced persons, such as during Hurricane Katrina, to fewer displaced persons. This is due to shipping container housing choices inherent modularity and arrangement flexibility. This form of shelter choice can become a permanent solution for the poor.

h. ***Cardboard Shelters:*** Cardboard and other alternative materials reveal many possibilities beyond those most frequently used in the construction of temporary emergency buildings, such as canvas-covered steel-frame tents (Fig. 7). Cardboard tubes enable quick assembly and disassembly of partition units in a gymnasium or even freestanding structures, without needing professional work, which is a key factor in emergencies. Apart from the above-mentioned structures built by Ar. Shigeru Ban, cardboard can play an important role in furniture design such as beds, seats and storage facilities that can be supplied to pre-cut sheets and with instructions for folding and assembly.

Fig. 8 Cardboard shelters. *Courtesy* Paper log house Kobe. Takanobu Sakuma

i. ***Rubber Shelters:*** Rubber can be recycled and used, among other items to make bricks (Fig. 8). In comparison to conventional bricks, rubber recycled bricks are simple to build and occupy immediately. Their low density is the most important advantage, resulting in very light blocks. The shelters designed with this technology can also remain in post-emergency times due to the high material strength compared to water-proof materials more commonly used for the construction of emergencies.

j. ***Bamboo Shelters:*** Bamboo is a highly flexible, bending and compressive fibre. It's the availability and rapid growth in most parts of the world is another valuable asset (particularly in hot climates). Bamboo is perfect for temporary structures like concrete frames, but also walls and roofs (Fig. 10). It offers the added advantages of fast mounting and permanent housing prospects when building emergency shelters. However, bamboo needs to be considered a construction material that has a good life and excellent mechanical characteristics, that chemical treatment is required before being used in construction to prevent rotting and infestations of insects. Another major challenge for constructing bamboos is the need to protect the components from rain and sunlight very well (Fig. 9).

k. ***3D printed recycled materials:*** Despite its comparatively high cost, 3D printing has spread over the years, proving to be a possibility for emergency shelter construction. For example, the Netherlands company DUS Architects developed a completely mobile 3D printer ("Kamer Maker") capable of printing whole rooms out of recycled materials (Fig. 11). In an emergency, however, 3D printers may be of specific use when printing tiny connecting components. The design of joints to enhance installation and the assembly of sections of various materials can be of great benefit.

l. ***Crates Sandbag Shelters:*** Used in many Ar. Shigeru Ban emergency shelters, sandbag-filled crates will serve as a shallow foundation for building structure (Fig. 12). Whenever possible, the crates can be used to protect from weather other building materials and prevent wetting. Using crates makes more sense when used to carry materials to the site. In such instances, all resources must

Fig. 9 Bamboo shelters (interior view) *Source* Shigeru Ban architects

Fig. 10 Bamboo shelter. *Courtesy* Shigeru Ban architects

Fig. 11 3D printed recycled materials. *Courtesy* ICON and new story

be considered during the process, from the site's arrival to its final destination. The combination of quick and easy interventions that can respond to the contingencies and demands of the affected population must be approached very seriously as they can help individuals in a very vulnerable situation, either due to illness or homelessness. Developing prudent and serious strategies and engaging

Fig. 12 Crete sandbag shelter. Courtesy of Colegio de Arquitectos del Ecuador—Pichincha Province

in extensive research into new materials and alternatives, including the use of local resources, is very critical.

2.3 Urge to Enable Victim-driven Intermediate Disaster Relief Shelters

To promote intermediate shelter policy structures, approach and execution play an extremely critical role. The adequate amount of intermediate shelters differs from the outcome of past studies. The biggest challenge is policy formulation to ensure proper use and improve mutual cohesion towards the fruitful implementation of intermediate shelters in disaster-prone areas. It is also difficult because on the one hand, as external organizations such as governments are seen to reach out to victims to support them at the same time, measures should not be such as withdrawing initiatives from the hands of local communities by disempowering them after the disaster. Mostly the tradition of supplying disaster relief shelters has resulted in such a conflicting outcome articulating the do not harm" maxim. It is therefore crucial that when the government formulates policies to promote and reinforce local community programs to empower them after the disaster, they should also be allowed to be part of their Habitat reconstruction as a continuum from relief shelter to their permanent housing if possible. Another essential element of facilitating the relief shelter is assistance at the required location, either in situ or moved. The following basic concepts originated from previous experience to promote the victims' intermediate shelter process after a disaster:

a. The rebuilding material that will be rescued from the destroyed houses must be reused to ensure that the additional building materials are usable after the disaster for speedy construction.
b. Incorporating practices and using local technologies to fine-tune them, ensuring that the system provides protection and separation from adverse climatic conditions in disaster and post-disaster situations.
c. The financing of owners must be improved as soon as possible.
d. Motivation and enabling local capacity to initiate and participate in the reconstruction process is equally critical.

3 Recommendations

The following are the recommendations for consideration during the decision-making and design processes of disaster-resistant shelters for effective and better performance during disaster and post-disaster scenarios:

a. ***Contextual Shelter Type:*** Post-disaster requires context-specific responses. No tent or universal prefabricated house works. Regional cultural disparities, livelihoods, lifestyle, socio-political set-up, available resources and damage scale need context-specific responses for reconstruction. Material and technology used must evolve within context-specific constraints and opportunities that foster local capacity. Materials commonly used by local societies are the most affordable option that can be effectively supported by local craftsmen, easily handled by families and improved living standards. Lastly, as permanent housing is constructed, these materials can be recycled. Getting out of branding shelter models fixation and accountability for surviving family's needs to be better addressed by empowering them to develop their context-specific solutions.
b. ***Facilitating Community Processes:*** The shelter approach includes several activities such as debris removal, ground levelling, rubble clearing, building material saving and assisting each other with equipment, labour and skills. The group should improvise their shelters. Experiences from past disasters have amply demonstrated that while areas affected can have little purchasing power, there are sufficient local resources available. The role of facilitating organizations is to promote certain processes and organize people to ensure the early recovery of each affected community member. The policy supporting community self-help with minimal government or NGO support works best. It harnesses peoples' creative capacities and accelerates the earliest dignified phase of intermediate shelter building for survivor families. By offering financial support, organizing for collective action, identifying and ensuring the involvement of the most vulnerable families, building community capacity and knowledge, developing materials, skills and know-how delivery systems, this can be done. People's involvement in recovery is not a matter of a collection of resources but a mindset; which sees them in the process as insightful, resourceful, competent and capable owners who can make decisions about time, money, labour, building materials, technology, design, layout, etc. which requires an attitude adjustment.
c. ***Timeliness:*** In case of any disaster the intermediate shelters need to be constructed within the first three to four months failing to cause dissatisfaction and psychological stress among the victims. Delivering even temporary shelters is marred by inadequate quantity, high costs, procurement delays and insensitive delivery. Evidence suggests that major contractors, prefabrication suppliers, play a relatively minor role in timely semi-permanent shelter construction. The method is most reliable, productive, fastest and satisfactory when powered by people themselves. Every organization's external participation could best be directed at improving peoples' efforts to build their intermediate shelters

by promoting gaps in the material, finance, expertise, technical guidance and needed craft tools.

d. ***Semi-permanent shelters policy framework:*** A progressive, community-based policy framework is significant. Indeed, a policy is required that guarantees people's right to adequate housing. Owner-driven policy mechanism means cash distribution, but also provides knowledge support systems, access to safe land with secure tenancy, required supplies, sufficient disaster-safety know-how and skills and rapid grievance redress. Under the 2005 Disaster Management Act, disaster management authorities have special purpose institutional vehicles to guide those processes and establish the framework required for essential resources such as finance, technology, technological know-how and building materials. For each of these resource aspects, the delivery process must be contextual, based on the disaster-affected region's socio-political setup and governance culture.

4 Conclusion

Disaster relief shelters must be provided for displaced populations as soon as possible in the event of a disaster, as losing a house means more than physical deprivation. Losing a house also means losing one's integrity, reputation and privacy and growing disease and pollution. Certain guidelines for these shelters need to be better addressed in the environmental, economic, technical and socio-cultural issues of such shelters, to improve the quality of life and needs of displaced persons. Thus, stakeholders should take into consideration the design factors of these shelters to ensure they are fit for their intended purpose before considering providing shelters for victims.

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Development of Emergency Food Aid Plan for Renal Disease Patients: A Vital Disaster Preparedness

Satesh Balachanthar and Lai Kuan Lee

Abstract The Kidney Community Emergency Response Coalition (KCERC) proposed the development of an emergency diet for dialysis-dependent patients as a key strategy for disaster preparedness. Thus, an accurate food demand prediction is necessary to inform both individuals, households and evacuation centres of the appropriate dietary recommendations during disaster for chronic kidney disease victims. The objective of the current study was to develop an emergency food aid plan (EFAP) that abates hunger and meets stringent nutritional requirements of the dialysis-dependent population during disasters. Two food databases were created separately in Kingsoft Spreadsheet according to predetermined scenarios using the following information: food prices, maximum weight of food consumed by the population, energy and nutrient composition of food and nutritional target or constraints of the population. Selection of food was based on the following scenarios: Ready-To-Eat (RTE), Emergency Food Basket (EFB) and Emergency Congregate Feeding (ECF) at the evacuation centres. Furthermore, cost-effective food aid was designed by employing linear programming and scenario development. This study established the designation of a nutritionally-appropriate, cost-effective, socially acceptable and sustainable emergency food aid plan for disaster preparedness and abatement. The estimated food cost for three days according to RTE, EFB and EFS scenarios would be MYR 6.16, MYR 6.46 and MYR 3.84, respectively. The current study is expected to serve as a national emergence nutrition policy reference and act as a framework for the government, non-governmental organizations and also the population at the household level for flood disaster management.

Keywords Emergency food aid · Dialysis · Disaster

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1 Introduction

Natural disasters such as earthquakes, hurricanes, tornadoes or floods may limit or delay access to dialysis. The Maramar Earthquake in 1999 and Hurricane Katrina in 2005 caused high frequency of missed dialysis sessions [1, 2]. Diet is paramount in the treatment of all stages of chronic kidney disease (CKD) including end-stage renal disease requiring dialysis. Hence, protein, electrolytes and fluid restricted diets enable survival until dialysis is accessible. The Kidney Community Emergency Response Coalition (KCERC) has proposed the development of emergency diet for dialysis-dependent patients as a key strategy for disaster preparedness [3]. The Centers for Medicaid and Medicare Services [4] and the National Kidney Foundation [5] were the pioneers in developing the 3-day emergency diet for dialysis-dependent patients. Meanwhile, Rossi and colleagues [6] have adopted the emergency diet for the Australian population requiring dialysis. However, the aforementioned organizations considered limited nutrients, primarily protein, sodium and potassium in developing the diet, prioritizing only acute post-disaster circumstances.

In Malaysia, monsoon and flash floods are the most severe types of climate-related natural disasters, with a flood-prone area of about 29,000 km, affecting approximately 4.82 million people and inflicting annual damage of USD 298.29 billion [7]. The December 2014—January 2015 flood was categorized as the worst flood tragedy in Malaysian history, majorly affecting states such as Kelantan, Terengganu and Pahang [8]. Approximately 384 end-stage renal failure patients from 20 affected hemodialysis centres in Kelantan received dialysis treatment [9]. According to the 22nd Report of the Malaysian Dialysis and Transplant Registry, the incidence and prevalence of dialysis-dependent patients in Malaysia were 234 and 1155 per million population, respectively [10]. Therefore, high frequency of flooding may increase the number of dialysis-dependent patients affected by the flood.

The objective of the current study was to develop an emergency food aid plan (EFAP) that abates hunger and meets stringent nutritional requirements of the dialysis-dependent population during disasters according to the Malaysian setting. Further, the selection and distribution of low-cost food aid tailored to CKD victims are still scarce. Hence, cost-effective food aid was designed by employing linear programming and scenario development.

2 Methodology

2.1 Creation of Food Database

Two food databases were created separately in Kingsoft Spreadsheet according to predetermined scenarios using the following information: food prices, maximum weight of food consumed, energy and nutrient composition and nutritional target or constraints of the population. Selection of foods into the database was based on the following scenarios: Ready-To-Eat (RTE), Emergency Food Basket (EFB) and Emergency Congregate Feeding (ECF) at the evacuation centres. The energy and nutrient composition of the food items were derived mainly from the Malaysian Food Composition Database [11]. Food items that were unavailable in the Malaysian database were obtained from the Singapore Food Composition Database [12] and USDA Food Composition Database [13].

2.2 Creation of Food Database

Three scenarios have been predetermined as follows.

2.2.1 Ready-To-Eat (RTE)

RTE scenario targets immediate post-disaster food requirements of the victims. Food items included in this scenario could be utilized during the absence of water, gas or power supply (acute conditions). A total of 46 food items with the following characteristics have been included: easy consumption without cooking, easy distribution, culturally feasible and readily available in the convenience stores. Examples of the food items include bread, biscuits, spreads, dried fruits, nuts, canned foods and packed beverages.

2.2.2 Emergency Food Basket (EFB)

EFB scenario caters for the provision of food baskets to the household in need. The food items can be used to cook food at home with the availability of water, gas or electricity supply. A total of 33 food items have been identified and targeted with the following characteristics: shelf stable foods such as dry foods, canned foods and packed beverages. Table 1 shows the food items used for both RTE and EFB scenarios.

2.2.3 Emergency Food Service (EFS)

EFS scenario targets congregate feeding at the evacuation centres and the foods are prepared and served by the emergency food service personnel, military personnel or voluntary organizations. The targeted food database could be used to create appropriate recipes to be served at the evacuation centres. For this scenario, 84 food items have been identified, where a combination of raw and RTE food items such as bread, biscuits, flour, rice, fish and seafood, poultry, fruits, vegetables and oil have been shortlisted (Table 2).

Table 1 Ready-to-eat (RTE) and emergency food basket database

Food items	Maximum food weight RTE (g)	Maximum food weight EFB (g)	Price per kg (MYR)
Bread, white	200	200	5.45
Bread, wholemeal	200	200	8.00
Biscuits, cream crackers	200	200	9.22
Biscuits, cheese flavoured	200	200	11.40
Biscuits, Marie	200	200	9.83
Corn flakes cereal	200	200	24.6
Oats, processed, tinned, dry	X	200	11.65
Instant noodle, dry	X	200	8.96
Wheat flour	X	200	1.35
Sardine in tomato sauce, canned	200	200	15.27
Tuna with mayonnaise, canned	200	200	24.81
Tuna in curry, canned	200	200	24.86
Tuna in water, canned, drained	200	200	21.57
Chicken curry, canned	200	200	18.75
Chicken kurma, canned	200	200	17.68
Prawn sambal, canned	200	200	18.75
Anchovies sambal, canned	200	200	18.75
Processed peas, canned	200	200	5.53
Baked beans in tomato sauce. Canned	200	200	6.70
Chickpeas, canned, drained solids	200	200	7.48
Red kidney beans in water, canned, drained solids	200	200	8.13
Longan in syrup, canned, drained	200	100	7.43
Lychee in syrup, canned	200	100	6.02

(continued)

Table 1 (continued)

Food items	Maximum food weight RTE (g)	Maximum food weight EFB (g)	Price per kg (MYR)
Pineapple, canned in syrup	200	100	6.19
Button mushroom, canned	200	100	10.56
Corn, whole kernel, canned drained solid	200	100	7.41
Corn, cream style, canned	200	100	6.94
Egg jam/kaya	60	X	14.25
Peanut butter	60	40	19.02
Mayonnaise, regular	60	X	14.04
Margarine	60	X	17.71
Cashew nuts, raw	60	100	64.89
Raisins, seedless	60	100	13.59
Dates, dried	60	100	32.50
Peanut oil roasted, unsalted	60	100	32.50
Milk, low fat, UHT	200	X	6.00
Milk, full cream, UHT	250	X	5.13
Soybean milk, packet,	250	X	2.53
Orange juice, sweetened, liquid	250	X	6.50
Chocolate malt drink, ready-to-drink	250	X	2.00
Bun, red bean	100	X	21.00
Bun, tuna	100	X	15.83
Bun, kaya	100	X	15.90
Bun, coconut	100	X	15.90
Bun, custard	100	X	17.50
Cream roll, chocolate	100	X	15.45
Cream roll, vanilla	100	X	15.45
Soup, cream of mushroom, condensed, canned	200	X	14.02
Soup, cream of chicken, condensed, canned	200	X	14.02

Sources of food price include Consumer Price Guide by North, Central, South and East Malaysia
Prices of food items unavailable in the price guide were obtained by market survey
Food price data was collected between June–December 2017

Table 2 Emergency food service (EFS) database

Food items	Maximum food weight (g)	Price per kg (MYR)
Bread, white	200	5.98
Flour, wheat	200	1.35
Rice noodles/*Kueh-Teow*	200	2.36
Rice noodles, wet	200	2.36
Rice noodles, dry	200	5.00
Rice, polished, raw	200	1.89
Chicken, whole, raw	200	7.08
Chicken, egg, raw	100	4.48
Anchovies, dried and cleaned	200	24.54
African bream fish, raw	200	8.49
Barred Spanish mackerel, medium	200	27.43
Black pomfret, raw, medium	200	20.05
Bonito tuna, raw	200	9.53
Catfish, raw, medium	200	6.98
Coral cod, raw, medium	200	21.75
Cuttlefish, raw, medium	200	17.73
Giant sea perch, raw, medium	200	16.82
Hairtail scad, raw, medium	200	8.91
Indian mackerel, raw, medium	200	11.98
Japanese threadfin bream fish, raw, medium	200	11.35
Jelawat, raw	200	12.99
Longtail shad, raw, medium	200	33.99
Malaysian river catfish, raw, medium	200	4.99
Mullet bluetail, raw, medium	200	12.99
Red snapper, raw, medium	200	28.16
Round scad, raw, medium	200	9.17
Sardine, raw, medium	200	7.99
Silver jewfish, raw, medium	200	9.69
Spanish mackerel, raw, medium	200	25.33
Stingray, raw, sliced	200	17.22
Threadfin, raw, medium	200	22.21
Trevally, yellow banded, raw	200	9.57
White pomfret, raw, medium	200	32.00
Wolf herring, raw, medium	200	18.61
Yellowtail, scad, raw, medium	200	12.87
Fish balls	200	12.50

(continued)

Table 2 (continued)

Food items	Maximum food weight (g)	Price per kg (MYR)
Soybean cake/*Taukua*	200	4.11
Bell pepper, green	200	9.22
Bell pepper, red	200	11.47
Bell pepper, yellow	200	11.51
Bitter gourd	200	5.49
Brinjals	200	2.89
Broccoli	200	10.13
Carrot	200	4.08
Cauliflower	200	6.39
Chinese cabbage	200	4.54
Chinese kalian	200	7.32
Chines mustard leaves	200	4.64
Common cabbage	200	3.50
Chinese radish	200	3.39
Cucumber	200	2.89
French beans	200	7.52
Lettuce	200	8.89
Mung bean sprouts	200	2.35
Okra	200	7.15
Garlic	50	7.99
Onion	50	2.73
Petai	200	16.67
Potato	200	2.94
Spinach	200	4.44
Swamp cabbage	200	4.24
String beans	200	5.57
Tomato	200	5.08
Apple, green, medium	200	10.00
Banana	200	4.25
Green pear	200	11.49
Chinese yellow pear	200	7.99
Guava	200	4.36
Dragon fruit	200	7.63
Honeydew	200	3.43
Mandarin orange	200	7.71
Navel orange	200	7.21

(continued)

Table 2 (continued)

Food items	Maximum food weight (g)	Price per kg (MYR)
Papaya	200	2.99
Pineapple	200	2.50
Watermelon, red	200	2.34
Canola oil	60	27.27
Corn oil	60	5.57
Palm olein oil	60	2.66
Sunflower oil	60	8.00
Blended oil	60	2.93
Butter	20	17.40
Margarine	20	19.96
Salt	1	2.14
Sugar, coarse	10	2.84

Sources of food price include Consumer Price Guide by North, Central, South and East Malaysia
Prices of food items unavailable in the price guide were obtained by market survey.
Food price data was collected between June–December 2017.

2.3 Food Prices

Prices of food were obtained from the Consumer Price Guide [14–17] released by the Ministry of Trade, Co-operation and Consumerism, Malaysia. The price guide was categorized into north, central, south and east Peninsular Malaysia. Hence, prices of the four regions were averaged prior to inclusion in the database. Additional information regarding the food prices was obtained from the website of hypermarket or in-store price survey. Bulk food prices and foods with promotion were excluded to minimize selection bias. Only the lowest-cost food of the same category was chosen to be included in the database.

2.4 Nutritional Constraints

The following energy and nutrient recommendations for dialysis-dependent patients by the National Kidney Foundation [5] were used in the diet optimization: 1800 kilo-calories (based on the recommendation for people with CKD), 40–50 g protein, 1500 mg sodium and 1500 mg potassium. Additional nutrients such as carbohydrate, total fat, saturated fat, cholesterol, phosphorus and dietary fibre were included in the optimization process based on the Malaysian Medical Nutrition Therapy Guidelines for CKD [18] (Table 3). For RTE scenario, optimization was performed for all the identified nutrients except fibre while for EFB and EFS scenarios, optimization was performed for all the identified nutrients. Since RTE scenario focuses on

Table 3 Nutritional targets and constraints used in the optimization

Nutrient	Target value used in the modelling	Recommended daily intake	Constraints imposed in the modelling
Carbohydrate (g)	257.0 (57%)	45–60% of total calories [18]	This nutrients must be equal to the target value
HBV protein (g)	25.0	40–50 g [5]	
Non-HBV protein (g)	24.5	Minimum 50% of HBV [18]	
	Total 11%		
Fat (g)	64.0 (32%)	25–35% of total calories [18]	
Sodium (mg)	1500.00	1500 [5]	These nutrients must be below or equal to the target value
Potassium (mg)	1500.00	1500 [5]	
Phosphorus (mg)	900.0	800–1000 [18]	
Cholesterol (mg)	200.0	< 200 [18]	
Saturated fat (g)	13.0	< 7% [18]	
Dietary fiber (g)	20.0	20–30 [18]	This nutrient must be equal to or above the target value

Recommended intake for protein, sodium and potassium was derived from “A guide for people on dialysis, Centers for Medicare and Medicaid Services”
Recommended nutrient intake for other nutrients was derived from “Medical Nutrition Therapy for Chronic Kidney Disease, Malaysian Dietetic Association”

immediate food requirements to satisfy hunger and restrict protein consumption, fibre optimization was excluded as it is more appropriate for long term dietary consumption.

2.5 Diet Optimization by Linear Programming

Diet optimization by linear programming is classically used to identify nutritionally adequate diets adapted to various sociocultural and economic contexts [19]. Linear programming is a technique that minimizes linear function of a set of variables while respecting multiple linear constraints, allowing price minimization of diet while fulfilling constraints introduced such as to ensure a palatable nutritionally adequate diet [20]. In this study, the objective function was set as the minimization of total food cost per day based on the following constraints: quantity of food that can be consumed by the population and the nutrient requirement of the dialysis-dependent population. The scenarios were modelled in Kingsoft Spreadsheets using the Simplex method. Refer to Briend et al. [21] for a detailed description of linear programming. The foods selected by the optimization process were then converted into approximate serving sizes based on the edible portion provided by the food databases.

3 Results

The total food cost to provide RTE food items during acute circumstances was MYR 6.16 per person per day by optimizing the following nutrients: carbohydrate, protein, fat, cholesterol, saturated fat, sodium, potassium and phosphorus. Meanwhile, by optimizing all the identified nutrients including fibre, the total food cost to maintain emergency food store or to provide emergency food basket was only MYR 6.46 per person per day. Similarly, total food cost to provide congregate feeding in the evacuation centres was relatively lower at MYR 3.84 per day. The three scenarios provided the following energy and macro-nutrient distribution: 1802 kilo-calories/day, 57% carbohydrate, 11% protein and 32% fat, respectively. Selected food items using the optimization process and the nutrients achieved were listed in Tables 4 and 5, respectively.

4 Discussion

The current study utilized linear programming in developing emergency food aid for CKD particularly dialysis-dependent victims based on the stringent recommendations by KCERC. The total food cost of the respective scenarios suggests feasible provision of emergency food aid for mass population during emergencies (below MYR 10 per person per day based on all three scenarios). The estimated food cost for three days according to RTE, EFB and EFS scenarios would be MYR 6.16, MYR 6.46 and MYR 3.84, respectively. In the current Malaysian setting, the cost of food products particularly canned foods and packed beverages are expensive and is considered luxury food, causing the total cost of RTE and EFB scenarios to be significantly higher.

For EFS scenario, the food items selected by the optimization process could be used at the evacuation centres to design feasible local recipes. Catfish could be prepared in the following ways: fried catfish or catfish fish curry served with cooked white rice. Wheat flour mixed with water and oil could be used to prepare flat bread while potatoes could be prepared by deep-frying or used in curry. Rossi et al. [6] used principles of menu planning and developed a 3-day emergency menu using dry and shelf stable food items according to the Australian setting and food supply. However, the authors acknowledged the challenges of implementing the designed menu as a bulk menu environment (e.g. evacuation centres). Meanwhile, Nghiem et al. [22] used diet optimization to identify lowest-cost food items for emergency storage in New Zealand. Although the indicated emergency foods satisfy the daily energy and nutritional requirements and have storage capacity with minimum spoilage, the study only catered for New Zealanders without any chronic disease. Our study remains the first to employ diet optimization to design lowest-cost EFAP for dialysis-dependent patients simultaneously addressing congregate feeding needs (provision of cooked meals) at the evacuation centres.

Table 4 Foods per person per day selected by the optimization process

Scenario	Foods selected by optimization process	Food weight (g)	Approximate serving size
Scenario EFB	White bread, medium	127	4 ½ slices
Total cost MYR 6.16	Marie biscuits	101	14 pieces
	Anchovies in chilli, canned	89	2 servings
	Mayonnaise, regular	53	3 ½ tablespoons
	Margarine	16	1 tablespoon
	Raisins	60	½ cup
	Dates	60	5 ½ pieces
	Soybean milk	106	½ cup
Scenario EFB	White rice, raw	104	½ cup
Total cost: MYR 6.46	Instant oatmeal, dry	57	1 ¼ cup
	Mackerel, canned	51	1 ½ piece, small
	Chicken kurma, canned	106	3 pieces, small
	Longan in syrup, canned	152	1 cup
	Chickpeas, canned	67	½ cup
	Dates	100	9 ½ pieces
	Blended oil	40	3 tablespoons
	Sugar	15	1 tablespoon
Scenario EFS	Wheat flour	36	4 tablespoons
Total cost: MYR 3.85	White rice, raw	200	1 cup
	Malaysian river catfish, raw, tail portion	150	2 pieces
	Potato, raw, medium	103	1 ¼ piece
	Guava, raw, large	200	2 slices
	Navel orange, aw, medium	183	1 whole
	Sugar	10	2 teaspoons
	Blended oil	46	3 ½ tablespoons
	Palm oil	7	½ tablespoon

Further, food products tailored for CKD patients are lacking in Malaysia. Therefore, a practical approach is adopted by selecting common food products available in the stores to devise the EFAP. The EFAP could also be used by victims with CKD Stage 3 and 4 requiring protein restrictions to delay the disease progression during emergencies. The EFAP design may serve as an emergency response policy for the government and voluntary organizations to maintain emergency food stores, provide

Table 5 Nutrients achieved by the optimization process

Nutrient	RTE	EFB	EFS
Protein (g)	24.5	24.5	24.5
High biological value protein (g)	25.0	25.0	25.0
Fat (g)	64.0	64.0	64.0
Carbohydrate (g)	257.0	257.0	257.0
Cholesterol (mg)	107.6	60.3	138.5
Saturated fat (g)	13.0	12.4	13.0
Sodium (mg)	1500.0	515.6	190.6
Potassium (mg)	1500.0	1258.9	1029.6
Phosphorus (mg)	707.2	900.0	759.5
Fibre (g)	–	20.0	20.0

emergency food baskets to disaster victims and provide congregate feeding in the evacuation centres.

Strength and limitations:

1. The food composition database does not provide high biological value (HBV) composition for the food items. Hence, we have separated the proteins into two components as follow: HBV (canned chicken, fish, seafood and milk) and non-HBV.
2. The diet optimization by linear programming could also be used to design daily dietary plans for CKD victims according to their nutritional status.
3. Different scenarios were modelled to accurately predict the type of food required and the total cost incurred using foods available in the market to provide effective and practical disaster response and relief.
4. Current food prices were used in the study. The prices may change in the future.

5 Conclusion

Emergency food aid is crucial to human beings in order to sustain life. Thus, an accurate food demand prediction is necessary to inform both individuals, households and evacuation centres of the appropriate dietary recommendations during disaster for CKD victims. This study established the designation of a nutritionally-appropriate, cost-effective, socially acceptable and sustainable emergency food aid plan for disaster preparedness and abatement. In particular, ready-to-eat and food service-oriented emergency food aid plans have been designed for acute water and electricity shortage and CKD victims who will be sheltered at evacuation centres. The current study acts as a framework for the government, non-governmental organizations and also by the population at the household level for disaster management.

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Understanding Disaster Preparedness Level in the South Indian City of Chennai

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Abstract Understanding and developing frameworks to quantify disaster preparedness levels is the first step that should be taken in the process of building a disaster-resilient society. This paper presents the use of Disaster Preparedness Index Tool to assess the preparedness level of each and every individual to face an impending natural disaster. It is a survey-based tool to analyze the preparedness indices of the respondents over psychological and various social factors. The Disaster Preparedness Index (DPI) is a valid and reliable tool that assess individuals on a three-level scale with index values ranging between 0–14. An attempt was made to quantify disaster preparedness of the South Indian city of Chennai by the application of the developed Disaster Preparedness Index Tool and the disaster mindset of the residents of the city was studied. The influence factors like psychological mindset and socio-economic conditions over the levels of disaster preparedness were analyzed and presented in the paper.

Keywords Disaster preparedness index (DPI) · Natural disasters · Chennai · Questionnaire · Reliability

1 Introduction

1.1 A Subsection Sample

The Sendai Framework for Disaster Risk Reduction adopted by the United Nations in 2015, mentions the importance of disaster preparedness and highlights preparedness as one of the five primacies for risk reduction. It identifies that preparedness can make the communities and individuals more disaster resilient. Disaster preparedness can help communities to recover and build back better after a calamity and preparedness

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alone can decrease the losses from disasters up to 40%. The present work of creating a tool to estimate disaster preparedness of individuals is a step taken in the direction of global disaster risk reduction in line with the UN Sendai framework. The lack of preparedness towards natural disasters is an important reason for destruction in the form of lives and properties. In a developing country like India, which is vulnerable to almost all kinds of natural disasters, the preparedness level is very less, which can cause severe losses following a major disaster. In the present study, an attempt was made to develop a tool that can be used to assess the preparedness level of each and every individual to face natural disasters. The various factors affecting preparedness among the diverse population in India are explored. Most studies investigate individual/household preparedness based only on their actions before and during the occurrence of a disaster and this study also looks into the psychological factors influencing the preparedness of individuals.

Chennai city is selected for the study based on the history of the occurrence of natural disasters in the city. The 2004 tsunami, which is still recorded as the single most devastating tsunami of all time, affected Chennai city as well, which took away hundreds of lives. Chennai city has experienced a lot of earthquakes and the last one measured 5.6 magnitude events in the year 2001. The 2015 Chennai flood cost about 400 lives and an economic loss of $300 million (approximately Rs 2,010 crore). The following year (2016), the city was affected by Cyclone Vardah. The high population and active construction work in the city also increase the extent of anticipated losses.

Preparedness has an important role in unifying practical and research works [1]. The capacity to save lives is a major implication of disaster preparedness [2]. Preparedness can save the lives of people to a great extent and reduce the losses by 40% [3]. Man Fung and Yuen Loke (2008) evaluated household preparedness and reported that the attitude of the family head is important for the household preparedness involving young children. They reported that the percentage of the well-prepared household is as low as 9.1%. Spittal et al. [6] developed a questionnaire including earthquake disaster mitigation and response planning.

The present study is unique compared to previous works, as a reliable tool is used for assessing the preparedness level of residents of Chennai city towards disasters, capturing the effects of psychological and socio-economic factors.

2 Methodology

2.1 Questionnaire Development

A thorough literature review was conducted as the initial step for developing the questionnaire. Sample questions were developed following previous studies across the world [4–9].

2.2 Sampling

The minimum size of the sample that is required statistically to study a population can be calculated from the Central limit theorem. The Central limit theorem can be used to determine the various sample sizes that are required for different population sizes, respective confidence levels (e.g. 95%, 99%) and allowable margin of errors. It was estimated that the city of Chennai with an average population of 8.5 million, requires a minimum sample size of 385 respondents, to study the population with a 95% confidence level and 5% allowed margin of error.

2.3 Field Survey

Four hundred 45 responses were recorded during the field survey conducted among the residents of Chennai. It can be seen that the sample size that we have chosen is greater than the required minimum sample size for the analysis (385, which was calculated by the Central limit theorem). The sample collected includes people who belong to various age groups, different educational classes, different employment groups, etc., to ensure that the sample collected was random and it is representative of the population.

People in scale interval 1 could be treated as "poorly prepared;" people in scale interval 2 as "moderately prepared;" and people in scale interval 3 as "well prepared" (Table 1). The mean score of the survey conducted throughout Chennai city is 5.43 and the standard deviation of the scores is 3.42. This indicates that the residents of Chennai city are moderately prepared to face a major disaster and a majority of the people are poorly prepared for any natural disaster.

3 Results and Discussions

The analysis of the survey responses clearly elucidates the fact that disaster preparatory levels are very poor amongst the residents of Chennai city. 53% of the surveyed respondents had very low preparatory levels, with scores in the range of 0–5 and only

Table 1 Score ranges and distribution of the disaster preparedness Index

Scale interval	Boundary	Distribution (%)	Preparedness level
1	0–5	53.48	Poorly prepared
2	6–9	35.05	Moderately prepared
3	10–14	11.46	Well prepared

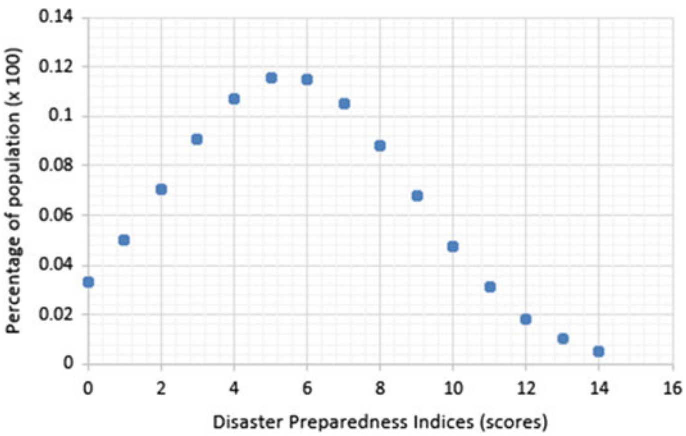

Fig. 1 Distribution of disaster preparedness indices in Chennai

11% of the total respondents have higher levels of preparation with a score range of 10–14. These figures clearly speak about the volume of people who are less aware of natural disasters. Therefore it is high time that appropriate campaigns and measures are taken to improve the levels of disaster preparedness.

The DPIs of the 445 respondents are plotted versus their respective frequency and the distribution shown in Fig. 1 was obtained. It can be statistically proven that the sample is random and representative of the population by looking at the shape of the curve as it resembles a normal distribution curve (bell curve). The distribution has a maximum DPI score of 5.43 and has a standard deviation of 3.42. The shape of the curve thus assures us that sampling was done without any bias and therefore it is representative.

3.1 Effect of Psychological and Risk Perception Factors on Preparedness Levels

Analysis of the responses of the well-prepared respondents (score range 10–14) is done to understand the main factors that lead to high levels of preparation amongst this category of people and our study has found that psychological mindset and risk perception were important factors. The analysis shows that 57% of well-prepared people are psychologically strong without any optimistic bias, normalization bias, lethargic mindset, responsibility transfer and other negative aspects. Disaster perception determines the disaster expectancy and 82% of people in this category expect a disaster to hit within ten years, because of which they are well prepared towards disasters. In contrast, the analysis of the responses of respondents with scores in the range of 0–5 shows that only 8% of poorly prepared people are psychologically strong and the rest 92% have an optimistic bias, normalization bias, lethargic mindset and other negative aspects. We can also see that 68% of the people don't expect a disaster to hit in the coming 50 years, because of which they are least prepared towards disasters. From the above facts, it is clear that for high preparatory levels, people must have the right psychological mindset and they must perceive the disaster without any bias. Hence the awareness and advertising campaigns must concentrate on removing the psychological myths and negative perceptions about natural disasters.

3.2 Effect of Demographic Factors on Preparedness Levels

The average preparedness index of different age groups is shown in Fig. 2. Disaster preparedness levels seem to increase with age except for a dip in the preparatory levels of people in the age group of 21–35. The majority of the people in the ages of 21–35 are working class: pre-occupied/ tressed with work, probably that might have led to the dip in the preparation levels. One way to address this problem is ensuring that mock drills and awareness workshops are conducted by the corporate organizations themselves, thereby imbibing the sense of disaster management and safety amongst the employees. Effect of levels of stress on the disaster preparation levels is again reinforced by the fact that the average preparedness indices of students (6.72) and house persons (6.61) are much higher than that of employed class (4.8), which is shown in Fig. 3. Students tend to be more aware of disasters because of the education curriculums they are currently exposed to. The house persons have higher values, possibly because they are calm and composed in making decisions as they are not exposed to extreme work pressures like the employed class.

Generally, households with old people, infants and pregnant women are more vulnerable in the sight of a disaster. Therefore special care and extra preparedness measures are to be adopted for adequate safety. But our analysis shows that such extra care is not taken and people actually don't perceive that they are more vulnerable and this is something which again should be addressed by the awareness campaigns. A total of 180 households out of 445 that are surveyed have at least one person with

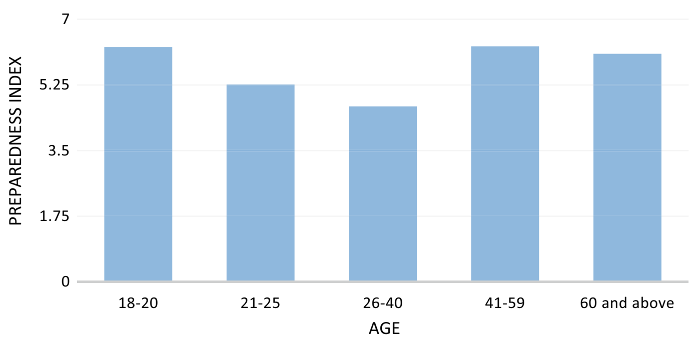

Fig. 2 Average preparedness indices of people versus age curve

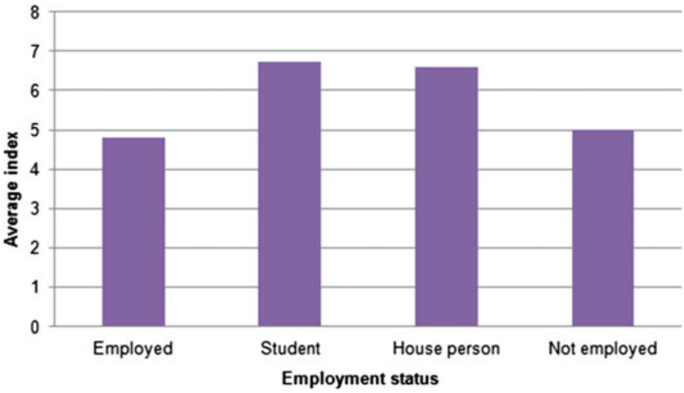

Fig. 3 Average preparedness indices of people versus their emp

age more than 60 years. Out of these, only 24% of the households have developed a family emergency plan, only 41% have procured a life insurance policy and only 26% have an emergency supplies kit. The above-mentioned actions are very much important in particular to the houses with old-age people, but more than 75% of these households are not prepared in this regard.

85.6% of the respondents identified 'Community group' as one of the main stakeholders in ensuring disaster safety. But only 22.24%, i.e. 99 households out of 445 have discussed community emergency warning systems. Effective measures must be taken in this regard to increase awareness about community warning systems.

3.3 Role of Various Media to Disseminate Disaster Information

The majority of the people, i.e. 329 respondents, receive disaster information through media (Television, Newspapers, Radio, etc.) and 260 respondents read about disasters from the internet. Only a meagre number of respondents get disaster information through workshops (34 people) and Fliers or posters (40 people). 12% of the respondents have never heard about disaster information through any of the above media, showing that penetration of the media is not maximum and certain sections of the society are deprived of the right disaster information. 91% of the respondents said that they have the capability to use social media to seek help during a natural disaster. Also, keeping in mind that 55 lakh people in Chennai use social media, we can infer that social media can be a more efficient way to disseminate disaster information than regular media.

4 Conclusions

It is known that preparedness plays a vital role in any serious hazards like earthquakes, tsunami, floods, etc. Along with smart, resilient infrastructure, a disaster ready and well-prepared community helps in reducing vulnerability. Preparedness alone can drastically decrease the huge losses incurred due to the various natural disasters. The present work is the application of a self-assessment tool, i.e. DPI for measuring individual disaster preparedness and analysis of the DPIs of the respondents over various factors of psychological mindset, socio-economic factors, etc. The Disaster Preparedness Index (DPI) is a valid and reliable tool that assess individuals on a three-level scale with index values ranging between 0–14. The DPI can assist individuals in knowing their present levels of disaster preparation qualitatively.

The assessment tool was tested for Chennai city, where a total of 445 respondents were surveyed. The analysis of the responses clearly elucidated the fact that 53.48% of the respondents were poorly prepared towards natural disasters and only 11.46% were well prepared. These figures suggest that disaster preparedness levels are very low and immediate measures are to be taken to improve them. Further analysis of the responses showed that disaster preparedness is affected by psychological factors and risk perception attitudes, which is one of the main conclusions of this study. 57% of the well-prepared respondents have a strong psychological mindset without any bias, whereas only 8% of the poorly prepared respondents were having a strong psychological mindset towards disasters.

The average preparedness levels of students and house persons was found to be 29% more than that of the working class who majorly fall in the age group of 21–35. This is a negative sign because the working class alone constitute to be 62% of the population and if they are less prepared, then the impact will be huge. The study also shows that around 12% of the respondents don't receive disaster information from any media sources, showing the inadequate penetration of awareness campaigns. The households with people above 60 years are more vulnerable. Surprisingly, the study shows that 75% of households with old people have not taken the basic actions towards disaster preparedness. Thus, this study quantified the disaster preparedness for the residents of Chennai city and throws light on the impact of psychological and demographic factors on disaster preparedness. The findings indicate that the society is poorly prepared and there is a need to increase the social awareness and preparedness measures to build a secure disaster-resilient society.

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Emergency Preparedness and Response—An Evidence-Based Onsite Audit Conducted in Two Hundred Organizations

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Abstract Preparedness of an organization to respond to emergency situations is now an integral part of any business. There are number of research studies conducted in *Emergency preparedness and response* which is now a prime interest for every stakeholder. The real challenge is every organization is different from other in terms of their capabilities and resources because *One-Size* doesn't fit all; hence, addressing emergency preparedness and response require a standardization which would be interpreted to suit the context of each organization. This research study is conducted by performing an onsite audit of 200 organizations to determine the conformance on the criteria of *Emergency Preparedness and Response"* in accordance with ISO 45001:2018. Researcher has spent 336 man-days onsite to perform an evidence-based audit as per ISO 19011 *Guidelines for auditing management system.* Research study in evaluation of compliance from a management system auditor perspective is inadequate, and hence, this research gap is addressed. Enough literature, methodologies, and technology are available to address the potential emergency situations across the world; the need of the hour is to avail necessary resources and implement the concrete plans in action out of stereotyped documented information. Research data were carefully analyzed using a simple statistical tool called *Jamovi.* Factors influencing effective implementation on the requirements of the ISO 45001:2018 standard were identified.

Keywords ISO 45001 · Emergency preparedness and response · Audit · OHS management system

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1 Introduction

Occupational health and safety management system are an integral part of most of the organizations across the world along with other management systems like quality, environment, and energy. The significance of occupational health and safety was realized over two decades while for high risk industries this was on top priority of their business ever since beginning of their operation. The occupational health and safety management system requirements took a shape of a standard with BS 18,000 series in 1999. Finally, BS 18,001 standard is now originated as ISO 45001 standard on occupational health and safety management system in the year 2018. Needless to mention the importance of each clause of ISO 45001 standard, however this research study is confined to one of the criteria determined in ISO 45001:2018 on "*Emergency Preparedness and Response*".

Emergency situation in any context is unwelcomed and undesired. There are various types of emergencies identified in general and/or in specific to nature and scope of industry sector; however, time and again new challenges prompt us to relearn from unexplored dimension to deal with uncertain emergencies. Many countries had established a dedicated authority for dealing with emergency situations. In some states, compliance to minimum requirements to *Health and Safety* makes an organization eligible to obtain the license to operate the business. The annual survey conducted by International Organization for Standardization [1] indicates that 38,654 certificates were issued across the world on ISO 45001:2018, which indicate the worldwide recognition and acceptance of the standard on *Occupational health and safety management system.* The highest number of ISO 45,001 certificates were issued in construction, basic metal and fabricated metal products, electrical and optical equipment, engineering services industry sectors, respectively. 35% of the ISO 45001 certificates issued in year 2019 was in an unorganized industry sector which are not listed under EA Code. ISO 45001:2018 standard provide an explicit criteria on the requirement for *Emergency Preparedness and Response* for the organizations to handle such unforeseen situations should they occur at any point of time.

2 Literature Review

Paula et al. [2] conducted a survey with a sample size of 91 participants from organizations in western Romania about the implementation of ISO 45001. In his research study, Paula suggested five action points for effective implementation of the ISO 45001 and highlighted the lagging factors such as competency and awareness. Tammepuu et al. [3] conducted a case study in on the integrated management system on emergency preparedness and response at Port of Tallinn. Tammeppu observed that fire and chemical risk were not inadequately addressed at the Port of Tallinn. Lauren et al. [4] conducted an hour long session on emergency planning and educational presentation on the convenience sample size of 45 employees under experimental group and a control group of 37 employees under pre- and post-assessment. Perception of the employees was monitored by analyzing their response on the questionnaire filled by both experimental and control group on their organizations level on emergency preparedness. Michael et al. [5] conducted a survey of 30 federal emergency management agency disaster sites to emphasize on disaster preparedness and response for persons with mobility impairment. The study period between 1998 to 2003 highlighted that the inadequate representation of the people with disabilities in emergency planning and other influencing factors such as lack of awareness, limited resources. Sheila et al. [6] have conducted a survey on a sample size of 227 organizations to assess to what extent organizations use information related to disaster for making decision. Ernest et al. [7] conducted a literature review with a sample size of 109 papers between 1975 to 2016 to study the community emergency preparedness and response in Saudi Arabia. Ernest has focused on emergencies arising out of global health threat and pandemic. Mariko Kageyama [8] has described in his research study about best practices adopted, networking, and training for protection of North American Natural Heritage. Mariko also state that the emergency plan is an active document which need to be regularly revisited and tested to confirm its adequacy otherwise the disaster planning would be ineffective and incomplete. Erkan Gunay et al. [9] conducted a research based on secondary data to study the emergency preparedness and disaster management in Turkish health care system. Tabish et al. [10] conducted a study on natural disaster and calamities their after effect and operational challenges to combat the emergency situations. Tabish suggests the enhanced usage of technology could effectively address the disasters.

3 Research Gap

From a management system, Auditor's perspective inadequate research studies have been conducted to determine the extent of conformance to the criteria on "Emergency preparedness and response" as per ISO 45001:2018; this research study is conducted to address this gap.

4 Research Methodology

The research data are gathered by conducting an audit of ISO 45001:2018 in certified organizations. An audit is performed to determine the conformance with the *occupational health and safety management system* after implementing the ISO 45001:2018 in an organization. This research study is confined to the definite conformity assessment variable on *"Emergency preparedness and response"* based on which a questionnaire is prepared. This research is descriptive in nature and based on objective evidence verified during an onsite audit. The structured questionnaire is prepared in accordance with the criteria determined in ISO 45001:2018 standard. Each question has five options to be selected based on Likert scale to demonstrate the extent of compliance. Researcher possesses necessary educational background and universally recognized certification on *Auditing and Occupational health and safety* which ensure the certification bodies to trust the auditor and qualify the auditor by allotting industry-specific EA Code to perform the audit with confidence. Researcher has meticulously selected the options from the Likert scale which is dependent on adequacy and suitability of the objective evidence. The outcome of the audit was quantified by using five point Likert scale which is denominated as given under.

4.1 Reliability Analysis

The Cronbach's alpha indicate the conformity assessment variables on *emergency preparedness and response* to be acceptable with $\alpha = 0.948$, which represent the acceptable consistency and a reliable questionnaire.

5 Results

Research data are collected and analyzed by using a simple to use software called Jamovi for statistical analysis. Table 1 indicates mean, median, and standard deviation of conformity assessment variable "Emergency Preparedness and Response" (Average: 3.71, median: 4, and standard deviation: 0.579). Analysis on sample size of 200 organizations preparedness and response on identified potential emergency situations was analyzed.

Table 2 represents the frequency of the Likert scale on which 58.5% of the sample conforms to the criteria on "*Emergency preparedness and response"* meaning 117 organizations out of sample size of 200 organizations has demonstrated adequate objective evidence on conformity to this requirement of ISO 45001. Likert scale 3

Table 1 Descriptive statistics

Emergency preparedness and response	
N	200
Missing	0
Mean	3.71
Median	4.00
Standard deviation	0.579
Minimum	3
Maximum	5

Table 2 Frequencies

Levels	Counts	Percent of total (%)	Cumulative (%)
3	70	35.0	35.0
4	117	58.5	93.5
5	13	6.5	100.0

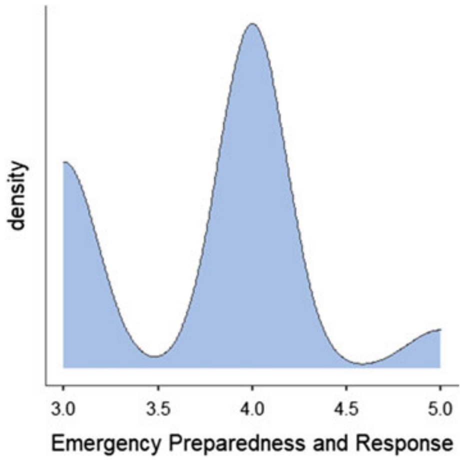

Fig. 1 Density distribution on Likert scale

point contributes to 35% of the sample meaning 70 organizations out of 200 organizations were neither complying nor non-complying where the researcher requires further evidence to determine the conformity. Only 6.5% of the sample where in which 13 organizations out of sample size of 200 organizations has demonstrated exceptional conformance to the requirement of the standard with the effectiveness of the actions taken.

Figure 1 represents the density distribution of the conformity to the requirements of the 200 sample organizations on a five point Likert scale. The audited sample organizations were selected from various industry sectors as per EA code classification to justify the homogeneity of the sample.

6 Conclusions

It has been noted that most of the organizations have fulfilled the minimum requirements to address *Emergency* in their organization by complying with applicable statutory and regulatory requirements. However, as an obligation toward compliance with many other requirements to ensure the organization's *Emergency preparedness and response* is updated and exercised to validate the arrangements made; the organizations to cater necessary resources and training to their employees. Adequate resources to be provided proportionate to the magnitude of consequences from the potential emergency situation, considering the complexity of the processes, literacy of the employees, vicinity, working conditions/hours, awareness, training, drills, equipment, regular inspection, frequent audits and size of the organization.

a. The emergency preparedness and response procedure is not a one-time documented information, but its a proactive and ongoing process which has direct correlation with the *Hazard identification and risk assessment.*
b. Potential emergency situations to be reviewed at planned frequency to determine the conformity on criteria of the standard.
c. Organizations to also emphasize on the proposed changes in organizations like processes, activities, operations, and other OHS management system while planning for the emergency preparedness and response.

7 Scope for Future Work

(a) Industry specific research study could be conducted to determine the adequacy and suitability of the emergency preparedness and response.
(b) Specific study could be conducted to determine necessary competency for the security personnel to handle emergency situations during non-working/business days.
(c) Compliance to the applicable statutory and regulatory requirements with respect to emergency preparedness and response could be studied.
(d) Cross country analysis could be conducted on success factors to handle various emergency situations.

Appendix

Questionnaire on "Emergency Preparedness and Response"

1. Does the organization established a process required to prepare and counter any potential emergency circumstance?
   - Major Non Conformance
   - Non Conformance
   - Inadequate evidence to determine conformance or non-conformance
   - Conformance
   - Strongly Conform with effectiveness of action
2. Does the organization implemented an established process required to prepare and counter any potential emergency circumstance?
   - Major Non Conformance
   - Non Conformance

- Inadequate evidence to determine conformance or non-conformance
- Conformance
- Strongly Conform with effectiveness of action

3. Does the organization maintain the established and implemented process required to prepare and counter any potential emergency circumstance?

- Major Non Conformance
- Non Conformance
- Inadequate evidence to determine conformance or non-conformance
- Conformance
- Strongly Conform with effectiveness of action

4. Does the organization made necessary arrangement for provision of first aid?

- Major Non Conformance
- Non Conformance
- Inadequate evidence to determine conformance or non-conformance
- Conformance
- Strongly Conform with effectiveness of action

5. Does the organization made arrangement for providing necessary training necessary for counter any potential emergency situation?

- Major Non Conformance
- Non Conformance
- Inadequate evidence to determine conformance or non-conformance
- Conformance
- Strongly Conform with effectiveness of action

6. Does the organization made arrangement for testing periodically planned emergency response capability?

- Major Non Conformance
- Non Conformance
- Inadequate evidence to determine conformance or non-conformance
- Conformance
- Strongly Conform with effectiveness of action

7. Does the organization made arrangement for exercising periodically planned emergency response capability?

- Major Non Conformance
- Non Conformance
- Inadequate evidence to determine conformance or non-conformance
- Conformance
- Strongly Conform with effectiveness of action

8. Does organization made arrangement for evaluating performance of planned emergency response capability?

- Major Non Conformance
- Non Conformance
- Inadequate evidence to determine conformance or non-conformance
- Conformance
- Strongly Conform with effectiveness of action

9. Does organization made arrangement for revising planned emergency response capability as deem necessary?

   - Major Non Conformance
   - Non Conformance
   - Inadequate evidence to determine conformance or non-conformance
   - Conformance
   - Strongly Conform with effectiveness of action

10. Does organization made arrangement for revising planned emergency response capability as after testing as deem necessary?

    - Major Non Conformance
    - Non Conformance
    - Inadequate evidence to determine conformance or non-conformance
    - Conformance
    - Strongly Conform with effectiveness of action

11. Does organization made arrangement for revising planned emergency response capability as post any emergency situation?

    - Major Non Conformance
    - Non Conformance
    - Inadequate evidence to determine conformance or non-conformance
    - Conformance
    - Strongly Conform with effectiveness of action

12. Does organization made arrangement for communicating all workers on their responsibilities and duties during emergency situation?

    - Major Non Conformance
    - Non Conformance
    - Inadequate evidence to determine conformance or non-conformance
    - Conformance
    - Strongly Conform with effectiveness of action

13. Does organization made arrangement to provide relevant information to all workers during emergency situation?

    - Major Non Conformance
    - Non Conformance
    - Inadequate evidence to determine conformance or non-conformance
    - Conformance
    - Strongly Conform with effectiveness of action

14. Does organization made arrangement to provide relevant information to all contractors during emergency situation?
    - Major Non Conformance
    - Non Conformance
    - Inadequate evidence to determine conformance or non-conformance
    - Conformance
    - Strongly Conform with effectiveness of action
15. Does organization made arrangement to provide relevant information to all visitors during emergency situation?
    - Major Non Conformance
    - Non Conformance
    - Inadequate evidence to determine conformance or non-conformance
    - Conformance
    - Strongly Conform with effectiveness of action
16. Does organization made arrangement to provide relevant information to emergency response service providers during emergency situation?
    - Major Non Conformance
    - Non Conformance
    - Inadequate evidence to determine conformance or non-conformance
    - Conformance
    - Strongly Conform with effectiveness of action
17. Does organization made arrangement to provide relevant information to government authorities during emergency situation?
    - Major Non Conformance
    - Non Conformance
    - Inadequate evidence to determine conformance or non-conformance
    - Conformance
    - Strongly Conform with effectiveness of action
18. Does organization made arrangement to provide relevant information to local community during emergency situation?
    - Major Non Conformance
    - Non Conformance
    - Inadequate evidence to determine conformance or non-conformance
    - Conformance
    - Strongly Conform with effectiveness of action
19. Has the organization considered needs of the interested parties in the development of emergency preparedness and response process?
    - Major Non Conformance
    - Non Conformance

- Inadequate evidence to determine conformance or non-conformance
- Conformance
- Strongly Conform with effectiveness of action

20. Has the organization considered capabilities of the interested parties in the development of emergency preparedness and response process?
    - Major Non Conformance
    - Non Conformance
    - Inadequate evidence to determine conformance or non-conformance
    - Conformance
    - Strongly Conform with effectiveness of action
21. Has the organization made arrangements to ensure involvement of interested parties during the development of emergency preparedness and response process?
    - Major Non Conformance
    - Non Conformance
    - Inadequate evidence to determine conformance or non-conformance
    - Conformance
    - Strongly Conform with effectiveness of action
22. Does the organization maintain documented information on the processes?
    - Major Non Conformance
    - Non Conformance
    - Inadequate evidence to determine conformance or non-conformance
    - Conformance
    - Strongly Conform with effectiveness of action
23. Does the organization retain documented information on the processes?
    - Major Non Conformance
    - Non Conformance
    - Inadequate evidence to determine conformance or non-conformance
    - Conformance
    - Strongly Conform with effectiveness of action
24. Does the organization maintain documented information on the plan for responding to identified potential emergency circumstances?
    - Major Non Conformance
    - Non Conformance
    - Inadequate evidence to determine conformance or non-conformance
    - Conformance
    - Strongly Conform with effectiveness of action
25. Does the organization retain documented information on the plan for responding to identified potential emergency circumstances?

- Major Non Conformance
- Non Conformance
- Inadequate evidence to determine conformance or non-conformance
- Conformance
- Strongly Conform with effectiveness of action

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Framework for Location-Allocation of Shelters for Evacuation During Cyclones

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Abstract Evacuation during disaster events is dependent on utilization of transportation, shelters, capital and human resources. In slow-onset events such as cyclones, use of these resources can be pre-planned and allocated based on the scenario of predicted level of disaster. For a developing country like India establishing such a method for prediction of demand and allocation of resources is required for floods and cyclones. This study attempts in addressing the need by proposing a framework for optimal allocation of shelters in evacuation scenarios where evacuation demand is calculated based on the current scenario of the hazard and the available capacity of destination shelters is known in advance. The framework utilizes a location-allocation model with constraints such as supply at shelters, travel cost between origin and destinations, risk clustering, etc. The methodology is applied to the coastal area of East Midnapur district in West Bengal. The study area falls in a low elevation coastal zone and is highly vulnerable to floods and cyclones. The proposed framework will help emergency planners in devising appropriate strategies to minimize the cost of operation by allocating resources efficiently for a successful evacuation.

Keywords Shelter location-allocation · Evacuation planning · Disaster management

1 Introduction

Evacuation is considered as one of the disaster preventive strategies. In floods and cyclones, evacuation requires sheltering people into resilient buildings at safer locations. These buildings can be hotels, specific purpose public shelters, friends and family homes, schools, colleges or other community facilities. School, colleges and other community facilities are used in addition to the event-specific shelters for meeting the huge sheltering demand and owing to requirement of these facilities for a short period of time around an event. The shelters to be opened alter decisions like

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the movement of evacuees, commodity supplies, emergency personnel and vehicles to be utilized thus influencing overall efficiency of the evacuation process.

In India, the Indian meteorological department (IMD) tracks and informs about the evolution of cyclones. This information is taken by the state disaster management authority which alerts the district administration to carry out response activities in wake of a cyclone warning. The district administration with several of its line departments is then responsible for carrying out major evacuation activities to shift vulnerable populations to safe locations. These vulnerable populations are identified as villages in district disaster management plans (DDMP) based on their nearness to coast and low lying area characteristics. District administration with the help of local volunteers disseminates warnings and requests people to evacuate. In some places, the National and state disaster response forces (NDRFand SDRF) are required to mobilize people and also assist them in evacuation. As the numbers of these response forces are less, the numbers of villages they can visit are limited and they mainly help in rescuing people during or immediately after a disaster. District administration states that, though people are compelled to evacuate, few people respond in early phases of cyclones and most of them evacuate only when an environmental condition in the surrounding becomes extremely worse. Since a large number of people evacuate without any vehicular assistance on the final day, they are at their own discretion to choose shelters and routes for evacuation. It has been reported that such practices have led to overcrowding in shelters as all evacuees choose the nearest shelter without considering its capacity. The decision makers and people remain helpless as most of the evacuation takes place under extreme weather conditions without any vehicular assistance and is largely unplanned. The events of overcrowding in shelters have been well described in case of major evacuations during cyclones for several states in India [1]. This overcrowding leads to poor experience of people in evacuation shelters and can lead to less people evacuating in a future event. Overcrowding can also lead to increased risk for loss of life given any hazardous event that occurs at the shelter. It also creates stress on other resources at each shelter that is needed for coping up with the disaster situation. It has been noted that secure shelters do increase evacuation rates [2]. Therefore, the decision makers should identify probable allocation strategies so that the evacuees could be accommodated over different shelters very efficiently minimizing the risk and overall cost of an evacuation operation.

This study attempts to identify evacuee-allocation methodology and the impact of staged evacuation on shelter allocation (in both permanent and temporary shelters) and on the travel distances arising from such shelter choices. The total numbers of evacuees are identified considering socio-economic factors, hazard parameters, place vulnerability and availability of infrastructure and services. This demand is then allocated to shelters based on the total travel distances (nearest allocation) given the constraints on shelter capacity. The evacuating population is identified into two different categories depending on their feasibility to walk to a shelter and their need for vehicle assistance in case the shelter is not walkable. An optimal allocation of evacuees is established giving decision makers a chance to plan the maintenance and opening of certain shelters. It will also help them in identifying villages that would need vehicular assistance and evacuee allocation to different shelters.

The following Sect. 2 covers the literature on shelter location-allocation problems studied for evacuations in different disasters. Section 3 describes model formulation of the problem undertaken in this study. Section 4 is about framework implementation in the study area along with results and discussions. Section 5 is the concluding section with future scope.

2 Literature Review

Generally, the number and locations of shelters that are to be made operational under a scenario are decided based on the evacuation demand generated, usable transport mode, shelter capacity, road capacity and lead time for the evacuation. Determining the shelter locations and evacuee-allocations are important components of evacuation planning process. For studying these components, it is important to conceptually define terms including stakeholders, evacuee categories, evacuation and shelter site definition, resource availability, communication and infrastructure among various other modelling parameters. Many of these components in previous studies have been modelled in ways such as single-level system optimal (SO) approach, bi-level approach with upper level SO for selecting shelters and lower level user equilibrium (UE) route selection and nearest allocation model of shelter selection, multi-objective, multi-period and scenario based formulations for finalizing shelter locations and allocations. These studies have included one or more of the following objectives like minimization of total travel time, total evacuee risk, total shelter operation cost, total clearance time, etc. The literature on shelter location and allocation problems has been reviewed by a few authors who brought out the critical issues existing in this domain in the context of evacuation planning [3].

A single-level non-linear mixed-integer programming problem was formulated for optimizing shelter location-allocation for the city of Virginia. The study considered sets of shelter location options and tested evacuation times to determine best allocation with minimum evacuation time. Shelter and routes were assigned at the system level which is debatable under disaster situations [4]. Another study proposed a bi-level problem as stakelberg leader–follower game where the authority decides on shelter locations to minimize total evacuation time at the upper level whereas at lower level evacuees decide their destination and routes. This type of allocation may appear to be realistic but decision of evacuees at times of disaster may not be optimal as they do not have an idea of the evolving disaster scenario [5]. The effect of road capacity changes in determining the capacity requirements and desirable shelter locations under hurricane conditions is also studied. The importance of a shelter location was measured by removing it and calculating the total evacuation time [6]. A bi-level scenario-based stochastic model has also been formulated. The modelled is proposed to minimize the maximum UE travel time by locating shelters at upper level and assigning evacuees to shelters and routes in a UE manner at the lower level [7].

Multi-objective approach is introduced in some studies for determining the number and location of shelters based on four objectives including minimization of travel distance, risk on the path, risk at shelters and time to reach hospital from these shelters. They also identified primary and secondary paths for evacuation to these shelters [8]. Shelter network planning and management problems as two-level stochastic problems have been studied wherein first stage locations, capacities and held resources of shelters are decided and in the second stage evacuees and resources are allocated to these shelters. The problem is solved using an L-shaped approach which yields bad quality solutions for integer value and non-linear relationships [9]. A hybrid bi-level model is also available wherein the upper-level problem assigns evacuees to shelters based on system optimality and at lower level, evacuees choose their routes to the assigned shelters [10]. A robust model with bi-level structure has also been developed. The objective was to determine optimal shelter locations and capacities, from a given set of potential sites, under demand uncertainty. At the upper level, decision makers determine the number and locations of shelters along with their capacities whereas, at the lower level, the evacuees choose shelters and routes to evacuate [11]. a multi-objective location-routing problem in line with [8] has been proposed by adding two additional objectives of minimizing number of shelters to be opened and total travel distance on primary and secondary paths [12]. A bi-level problem (stackelberg game) in which the upper-level decision to open a shelter is made by the emergency managers and the lower level program is based on dynamic user equilibrium (DUE) where the users try to minimize their individual travel time. Several hurricane scenarios are solved to identify long-term and short-term recommendations on maintenance and opening of shelters for hurricanes. In this paper, they have assumed that all the shelters should be outside the affected zone, while in real world people can be sheltered in affected zone itself but they only need more resilient buildings to stay in Li et al. [13]. A multi-period, multi-criteria mixed-integer program assuming a system optimal approach was proposed. The criterion's used were evacuation time, the number of shelters to be opened and the risk exposure of the evacuees [14].

Most of the evacuation models studied reveal that they focused on self-evacuation of people (using personal transport) in different kinds of events. Some studies modelled events like hurricanes and floods which allowed for use of vehicles and are mostly car-based models while in some other situations like fire and earthquake that are sudden events self-evacuation was mostly by walk. The user equilibrium approaches with some system wide constraints apply to these problems and are more realistic when a majority of evacuees have to depend on personal modes to travel. Later few studies developed recognizing the needs of disadvantaged in terms of special needs population and economically weaker evacuees who require vehicular assistance from the authority. These models focused on bus-based models and integrated modelling approaches. All these studies try to optimize shelter allocation and traffic assignment simultaneously but rarely identify the impact of staging on allocations and travel distances. It is seen that evacuation based on staging generates less load on networks at a particular time period thereby speeding up the evacuation.

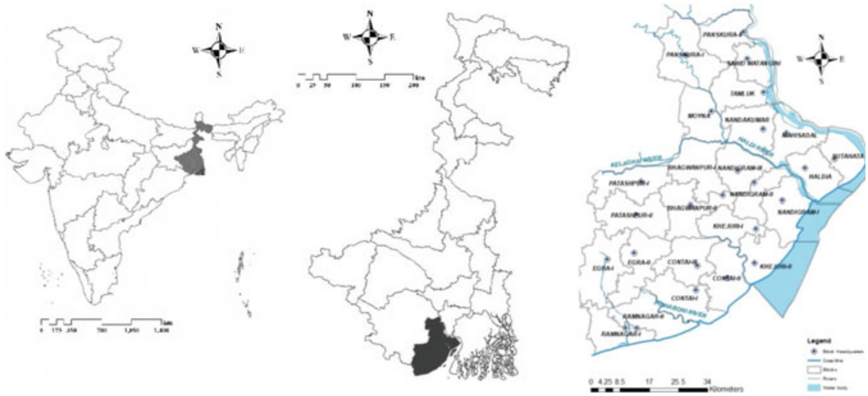
This paper studies the impact on travel distances due to staged evacuation strategies by choosing shelter location and allocations based on nearest allocation for complete evacuee population and cluster wise population. Evacuation in stages should be considered as in situations like cyclones that strike the coast first and then move into inlands thereby posing maximum risk to the population closer to the coast. The failure of closest coastal population to evacuate for reasons such as congestion on road networks or occupied shelters might prove to be more fatal. Hence, strategies and considerations that should be made in planning evacuation in these cyclonic events are discussed.

3 Framework Implementation

3.1 Study Area

Purba midnapur district is located in the southern part of West Bengal and covers an area of 4713 sq km. It shares boundary with the Bay of Bengal on the east with Paschim Midnapur district surrounding it from western and northern part and Orissa is on its southwest. It has 25 Community development blocks divided among four sub-divisions. These sub-divisions are Tamluk, Egra, Haldia and Contai with only Tamluk having two municipalities and others with one each. The road network comprises 829 links and 535 nodes on a total of 2430 kms length. This region is 5–7 m above mean sea level and average slope is 0–5° [15] and is classified as Low elevation coastal zone (LECZ). The impact of cyclones and flooding is high here because of the topographic and peoples socio-economic condition in this region.

According to the 2011 census the district has a population of approximately 51 lakhs. It has a population density of 1081per square kilometre. The district has urban population of around 11.63% and is majorly rural. The region is highly vulnerable to cyclones and floods and has faced major cyclonic events in recent years like AILA 2009 and Amphan 2020. For AILA cyclone the state government reported that from this cyclone around 61,000 houses collapsed and more than 132,000 houses were partially damaged.



3.2 Modelling Approach

The illustration has been modelled in following two steps: firstly the risk analysis is carried out for villages to identify vulnerable populations for evacuation; secondly, evacuees from risk analysis are allocated optimally to shelters designated by the authorities to be used in disasters.

3.2.1 Risk Clusters

Risk analysis is based on the parameters of cyclone AILA which occurred in 2009 over the study region. Cyclone impact and physical susceptibility parameters that have high impact on evacuee generation are used for risk calculation [16].

For cyclone impact wind profile and storm surge of AILA cyclone is used. The wind profile is taken from radar maps and secondary sources showing the maximum sustained wind speed profiles of cyclones at different points along its path [17]. The storm surge values and inundation extent is from the study which used IITD model to mark the inundated areas from AILA cyclone [18].

Physical susceptibility of villages and towns is calculated based on three criteria: the distance from coast, distance from major rivers and flood proneness of the area. All villages and towns close to the coast; river and falling in the flood-prone area are ranked higher in physical susceptibility. Coastal buffers are based on the location of villages and towns from the coast in 5 km intervals and up to 20 km from the coast. The areas along rivers directly connected to sea can experience flooding from overflow of rivers caused by storm surges. Buffer along major rivers are considered at 0.5, 1, 2 and 3 km distance. Flood-prone areas are identified based on historical data on riverine and coastal flooding. Areas located in the flood zone are ranked higher than areas that are situated outside [16].

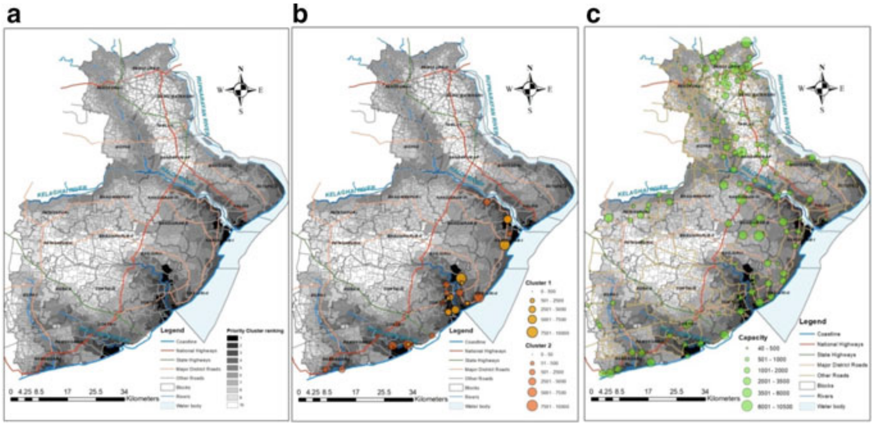


Fig. 1 **a** Priority Clusters. **b** Evacuation demand in Cluster 1 and Cluster 2. **c** Shelter nodes with capacity

GIS-platform is used for the analysis creating rank for villages and towns falling under different threat levels. The proximity of villages and towns from threats while assigning the ranks. Areas closer to the threat are placed in high impact zones and the rank decreases for areas away from threat. These ranks of villages and towns are aggregated using Thieler and Hammar-Klose (1999) methodology to give cyclone impact, physical susceptibility and evacuation area scores. The scores of cyclone impact ranged from 0.7 to 2.12 values with a lower value representing an area to be under high impact. The scores of physical susceptibility range from 0.57 to 4.08 values with a lower value representing an area to be highly susceptible. The final evacuation score ranges from 0.45 to 2.08. The study categorized priority zones using natural Jenks classification which defines categories such that each interval is statistically different from the adjacent interval. The risk values of all the polygons are divided into priority clusters based on similar risk values among the group of villages and towns given in Fig. 1a. After identification of villages and towns in different priority levels, the evacuation demand is calculated.

Determining evacuation population is necessary for planning logistics and shelter arrangements.

Numerous methods have been used to identify evacuation populations among those are the direct participation rates, correlated hazards, socio-economic and demographic variables to evacuation decisions, populations identified in disaster management plans, etc. Few applications of these methods are found in studies that have used evacuation populations given by HAZUS–MH [13], percentage of people evacuating based on three factors its population, the landfall location and the hurricane category [9], considering half of the population [6] or total population [5] of an evacuation planning zone were taken for their study.

The number of evacuees for this study are identified based on their access to infrastructure and the housing condition [16]. Access to infrastructure facilities like

Table 1 Number of administrative units in each cluster and their evacuation demands

Cluster	Number of units	Evacuation population
1	56	43,704
2	97	57,330
3	186	139,086
4	232	199,834
5	324	325,205

medical services and pucca roads within 5 kms of the village or town was considered. This is based on the premise that the area would become unserviceable after a cyclone and it will be challenging for people to get medical support after a cyclone and also rescue operations will be hindered because of unavailability of pucca roads. The evacuation population is located at village centroids are attached to the nearest nodes on road network. The following Table 1 shows the number of units in different clusters with the evacuation population.

The identified cluster wise evacuation populations are mapped to nearest nodes on the network. The evacuee populations are divided into two travel mode categories. The first category of evacuees will travel by foot for distance less than 2 kms. The second type of evacuees takes public transport for evacuation if the distance is more than 2 kms. The mode used by evacuees can also include use of personnel vehicles but is not considered in this study. The mapped node (origin) contains the total demand generated from each priority cluster.

The number of clusters for evacuation can be chosen by the emergency manager whose based on the area under impact considering the intensity and magnitude of the hazard. The evacuees from clusters 1 and 2 are represented on the nearest network node as shown in Fig. 1b. Similarly, volumes of evacuees from different nodes for each cluster can be identified. The volume of population evacuating from respective areas is used in further evacuation analysis.

3.2.2 Shelter Allocation

Two types of shelters are present, one of permanent nature which is designed specifically for disasters like floods and cyclones. Second type of shelter is facilities (like schools, hospitals, hotels) which are built for different use but used as shelters in emergencies. These shelters totalled 472 in the district as per district disaster management plan (DDMP). A total of 391 shelters could be located and were geocoded. These comprise 73 permanent shelters and 318 temporary shelters along with their respective capacities as shown in Fig. 1c. The capacity of shelters was given for some of the community development blocks in district disaster management plans while for other shelters capacities were assigned by considering the average capacity of similar types of shelters. For example, temporary shelters like high schools whose capacity are not given were assigned a value of 500 which is close to its observed average capacity. There were three community development blocks whose shelter details were not given and there are blocks that do not have permanent shelters. This may be because those blocks may not be vulnerable to these events or it can be due non-compilation of information on shelters.

Very similar to clusters mapped on origin nodes, the potential shelter locations and their capacities were identified and geocoded for the study area. These shelters are expected to be maintained and can be used during disaster events for meeting evacuation demand. These geocoded shelters are loaded onto the nearest nodes (destinations) giving the total supply at a particular node on the network.

Staging of evacuation is important as people are exposed to different levels of risk based on the place, hazard and socio-economic characters in a region. The measured risk helps in spatially locating the impact of hazard. It gives areas that would be at high risk and may be under great impact. The lead time of the hazard impact on a place combined with risk levels is studied to give priority to evacuation of specific areas. Thus by defining priority clusters the evacuees from the most risky areas are evacuated first and are not left behind at the mercy of network dynamics.

The optimization problem is formulated with the objective to find out optimal shelter allocations while minimizing the overall travel distance between the origin and destinations. Based on the set objectives in a study for shelter allocations, it is necessary to define concepts like evacuation population, shelter locations, shelter capacity, geocoded network, etc. One of the challenges in developing a model is access to data; in this paper easily available secondary data is used. The criteria selected for this study and how they are modelled is described here. This allocation has constraints related to shelter capacity. The decision variables are a number of evacuees allocated to different shelters. The problem is modelled by taking help of ArcGIS and R software. ArcGIS, which is a user-friendly interface, was used to spatially present the locations of shelters, evacuation demand and routes. It helped in creating network datasets and visualization of solutions to enable managers for devising strategies in location and allocation of resources. *R* software is used to solve the linear programming (LP) problem. The LP model is defined as minimizing (Z) the total travel distance where X_{ij} ($i = 1, 2, \ldots, n, j = 1, 2, 3, \ldots, m$) be the number of evacuees to be allocated from origin i to shelter j and C_{ij} is the travel distance between i and j. The mathematical form of this linear programming formulation is

$$\text{Minimize } Z = \sum_{j=1}^{n}\sum_{i=1}^{m} C_{ij}X_{ij}$$

Constraints:

Origin Demand side constraint: the sum of allocated evacuees must not exceed the demand from a node.

$$\sum_{j=1}^{m} X_{ij} = D_i \quad \text{For } i = 1, 2, \ldots, n$$

Destination shelter supply side constraint: the sum of allocated evacuees to each shelter must not exceed its capacity.

$$\sum_{i=1}^{n} X_{ij} = S_j \quad \text{For } j = 1, 2, \ldots, m$$

$$X_{ij} \geq 0, \text{ for all} i \text{ and } j$$

4 Solution Procedure

The travel distances are obtained using ArcGIS in the form of O-D matrix. Shelter capacities, evacuation demand and travel distances are put in simplex tableau form. The values of decision variables are derived using simplex method developed by George Dantzig in 1947. Simplex method is an iterative method where the constraints are firstly mapped to find the basic feasible solutions. In the iterative process, the allocations are made in such a way that it minimizes the objective function in each step. When the solution reaches the minimum value the iteration stops and solutions are obtained. The objective of this paper is to minimize the total travel distance while allocating evacuees to shelters.

Evacuee allocation is tested for staged allocation and one-time allocations to identify the case where the overall travel distance is less to save the cost incurred during evacuation. In first scenario, the evacuee population was considered for two subsequent priority clusters. The optimal allocation of evacuees to shelters for the first priority cluster was calculated and the remaining shelter capacity was used in the next iteration for allocation to the second cluster. This step has to be repeated if there are more subsequent clusters but as in this study, only two clusters are considered the problem was solved twice. In addition to this type of allocation to priority clusters, another scenario where priority clusters were combined into one evacuation area and the total evacuee population was assigned to shelters. The optimal allocation of combined evacuation population is calculated using the same optimization technique.

The decision values, i.e. the allocated evacuees are all integers because the inputs to model (node-wise demand and supply) are in integers. The solutions for these two scenarios have been compared based on the travel distances produced from allocations of evacuees to shelters.

5 Results and Discussions

The LP approach is implemented for the East Midnapur area. We separated the vehicle users from non-vehicle users based on the assumption criteria that all the

Table 2 Mode-wise evacuation demand for clusters

Evacuation mode	Clusters1 and 2	Cluster 1	Cluster 2
No-vehicle	27,578	11,131	7912
Vehicle assistance	73,456	32,573	49,418
Total	101,034	43,704	57,330

evacuees with evacuation distance less than 2 kms will evacuate on foot while others will use vehicles to go to a shelter. The clustering of risk generated a total of 43,704 evacuees in cluster 1 and 57,330 evacuees in cluster 2. Out of these, 32,573 evacuees of cluster 1 and 49,418 evacuees of cluster 2 have to travel to distances longer than 2 kms needing vehicular assistance. Under scenario 2, with combined demand, a total of 101,034 evacuees were generated and of these 73,456 evacuees need to evacuate using vehicles. Table 2 shows the mode-wise evacuation demands for clusters.

For both the scenarios, the optimal solution showed same number of shelters being used for allocation. These shelters were located on 57 nodes which minimize the overall evacuation travel distance in both scenarios. A total of 121 shelters with 53 permanent and 68 temporary shelters are part of these nodes. The assignments of evacuees differ for some of the nodes while others have same assignment. The block-wise evacuation demand and allocation is shown in Fig. 2 and in Table 3. The evacuation demand is concentrated in eight blocks that are adjacent to the coast while the allocation is distributed to 13 blocks including both the coastal and inland blocks. It can be because of these reasons that the evacuees from a block evacuate to nearest shelters which are in adjacent block or because the shelter capacity in their blocks is insufficient or the shelter is attached to node of adjacent block.

In combined allocation, the number of evacuees below 2 kms increased owing to simultaneous availability of nearest shelters for cluster 2 evacuees which would otherwise be occupied by cluster 1. We multiply the travel distance of vehicle-using

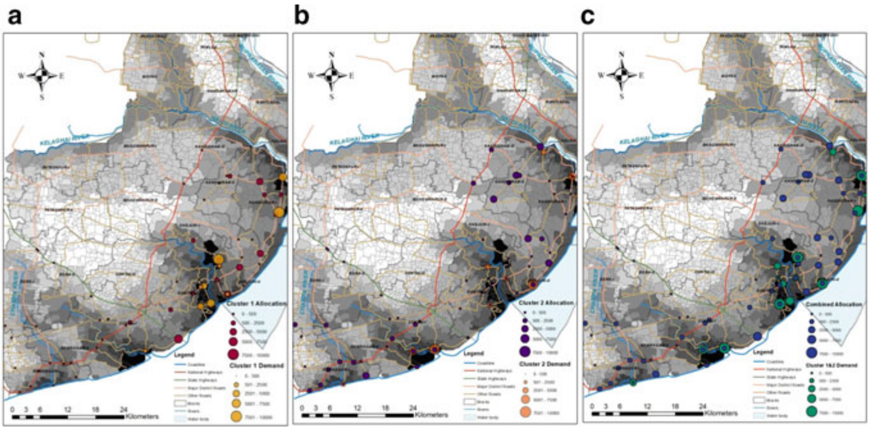


Fig. 2 Demand and shelter allocations. **a** Cluster 1. **b** Cluster 2. **c** Combined 1 and 2

Table 3 Block-wise evacuation demand and shelter allocations

Block name	Evacuation demand			Shelter allocation		
	Cluster 1 and 2	Cluster 1	Cluster 2	Cluster 1 and 2	Cluster 1	Cluster 2
BHAGWANPUR-II	0	0	0	2500	0	2500
CONTAI-I	11,789	1101	10,688	15,900	9884	6016
CONTAI-II	26,409	15,383	11,026	6600	6600	0
EGRA-I	0	0	0	2500	0	2500
EGRA-II	0	0	0	1500	0	1500
HALDIA	59	54	5	59	54	5
KHEJURI-I	27,893	13,448	14,445	4000	1148	2852
KHEJURI-II	0	0	0	21,400	15,000	6400
NANDIGRAM-I	21,294	13,706	7588	10,500	10,500	0
NANDIGRAM-II	3413	0	3413	16,700	506	16,194
NANDIGRAM-III	0	0	0	1481	0	782
RAMNAGAR-I	5105	0	5105	11,994	0	12,693
RAMNAGAR-II	5072	12	5060	5900	12	5888
Total	101,034	43,704	57,330	101,034	43,704	57,330

evacuees and the number of evacuees to generate the total evacuee distance travelled from a node by vehicle users. The total evacuee distance to be travelled by vehicle users in case of cluster 1 is 281352 kms and 1028858 kms for cluster 2 evacuees. This distance in case of simultaneous allocation is 1222698 kms which is less than total of cluster 1 and cluster 2 by 87512 kms. It shows that simultaneous allocation reduces the total travel distance significantly. The decision to retain this allocation lies in the fact that the evacuation is completed before the lead time. The origin and destinations with their respective allocations and distance of travel are shown in Tables 4, 5 and 6. For example in Table 4, first part of the table shows that origin two generates 1742 evacuees and according to the proposed method these evacuees are allocated to shelters at node 1 and node 2 with 844 and 898 evacuees respectively. It also shows the distance that evacuees would have to travel with this type of allocation.

6 Discussion

Though clusters are defined for prioritizing evacuation zones, evacuees of different clusters may have to pass through the same nodes and arcs for reaching a shelter as seen in this study. Thus it is necessary to study the node vulnerability and population routing through a particular node to make informed decisions such that the distribution and evacuation time are not affected by any disruption in the network.

Table 4 Combined Clusters 1and2 node origins and destinations with allocated evacuees and distance

S No.	Cluster 1 and 2 (O-D)	Allocated evacuees	Distance (km)
(I)	*2*	*1742*	
	1	844	3.34
	2	898	0.00
(II)	*3*	*2943*	
	3	300	0.00
	6	853	9.72
	7	500	13.97
	13	1290	6.45
(III)	*6*	*420*	
	2	273	3.73
	6	147	0.00
(IV)	*8*	*6*	
	11	6	11.64
(V)	*19*	*5060*	
	4	4150	17.74
	13	910	18.57
(VI)	*20*	*9123*	
	2	1329	30.30
	11	494	19.12
	15	2500	20.54
	19	1200	4.72
	20	2400	0.00
	353	1200	9.15
(VII)	*26*	*274*	
	26	274	0.00
(VIII)	*28*	*693*	
	28	693	0.00
(IX)	*36*	*1699*	
	36	1699	0.00
(X)	*53*	*7997*	
	21	500	26.13
	26	926	23.99
	28	771	10.11
	34	2400	18.39
	47	1000	8.01
	53	2400	0.00

(continued)

Table 4 (continued)

S No.	Cluster 1 and 2 (O-D)	Allocated evacuees	Distance (km)
(XI)	*55*	*438*	
	35	118	42.34
	356	320	20.33
(XII)	*56*	*6417*	
	28	4536	12.29
	36	701	19.52
	39	500	23.36
	65	500	29.36
	356	180	25.02
(XIII)	*70*	*2839*	
	70	2839	0.00
(XIV)	*73*	*1583*	
	73	1000	0.00
	80	500	8.49
	101	2	32.61
	142	81	34.22
(XV)	*75*	*1020*	
	75	1020	0.00
(XVI)	*76*	*3702*	
	30	500	43.61
	33	1000	38.45
	75	180	0.70
	142	541	37.04
	174	1481	45.24
(XVII)	*77*	*8350*	
	70	250	3.93
	77	2200	0.00
	99	3200	5.81
	104	2700	8.06
(XVIII)	*83*	*4654*	
	70	1811	4.27
	83	2200	0.00
	95	643	5.35
(XIX)	*94*	*3380*	
	35	1382	49.16
	101	498	39.39

(continued)

Table 4 (continued)

S No.	Cluster 1 and 2 (O-D)	Allocated evacuees	Distance (km)
	106	500	43.61
	107	500	44.04
	509	500	2.71
(XX)	*97*	*2431*	
	95	2057	5.93
	97	374	0.00
(XXI)	*122*	*7604*	
	119	2000	0.82
	132	1500	6.35
	133	1085	3.76
	144	2932	9.56
	175	87	17.86
(XXII)	*130*	*887*	
	133	887	1.14
(XXIII)	*133*	*28*	
	133	28	0.00
(XXIV)	*138*	*59*	
	148	59	7.40
(XXV)	*150*	*12,775*	
	127	2207	20.33
	143	2500	15.63
	144	1068	4.79
	150	1000	0.00
	151	3000	11.02
	152	3000	17.83
(XXVI)	*163*	*3413*	
	175	3413	1.82
(XXVII)	*365*	*9619*	
	97	626	1.68
	102	500	7.14
	111	1000	14.80
	113	3000	11.41
	127	2493	30.08
	365	1000	0.00
	531	1000	9.68
(XXVIII)	*509*	*1878*	
	142	1878	38.28

(continued)

Table 4 (continued)

S No.	Cluster 1 and 2 (O-D)	Allocated evacuees	Distance (km)
	Total	101,028	

Under different strategies, we found that the total vehicle travel distance is more in case of staged allocation. Hence, from the perspective of system optimality, the allocation for all zones to shelters should be done using all the clusters population at once and it could be modified according to based on the traffic parameters and road capacities in later steps. But notifying the evacuation start time for clusters must be according to the priorities as it is rational to first evacuate clusters closest to the hazard.

The model identified the number of shelters that is to be opened based on shelter capacities. However, the road capacities and traffic characteristics that are important in determining the total travel time for clearing evacuees have not been incorporated. The inclusion of these components can affect the allocation in several ways. For example, congestion or disruption on a network can lead to reduction in road capacities or road closures forcing people to choose different routes and even changing their destinations. Since evacuation is time bound and has to be completed within a specific time period (lead time) these allocations can differ owing to travel time to a shelter under routing strategies followed by evacuees. There can be routes longer than the shortest routes but taking similar evacuation time, hence a more comprehensive understanding is gained when we consider the time aspect of evacuation.

7 Conclusion

The methodology was applied to the East Midnapur district to study the impact of allocation strategy on travel distances for both the permanent and temporary shelters. It identified those shelters which can be operated by emergency managers under such events to minimize the cost of running the shelters and the total cost of travel. We can know from the shelter allocations that staging–evacuation allocation will lead to an overall increase in travel distance compared to one-time allocation. Hence the allocation should be done for all clusters at once and the respective number of evacuees can leave for destinations in a staged manner.

The study provided a tool for the emergency managers for long-term shelter location planning and allocations during evacuation based on secondary data. It also helps in the process of staging evacuation in major cyclone events or tsunamis which can have an overwhelming impact on coastal population. The model can be used to forecast mode-specific evacuees with their destinations.

Further studies based on traffic assignment problems will provide more insight into the allocation distribution strategy. Choosing permanent shelters for evacuation saves the cost of repair and preparation of buildings for this specific purpose. So,

Table 5 Cluster 1 node origins and destinations with allocated evacuees and distance

S No.	Cluster 1 (O-D)	Allocated evacuees	Distance (km)
(I)	*8*	*6*	
	353	6	1.68
(II)	*20*	*1101*	
	20	1101	0.00
(III)	*53*	*4439*	
	28	8	10.11
	36	1469	17.34
	47	562	8.01
	53	2400	0.00
(IV)	*55*	*438*	
	47	438	5.50
(V)	*56*	*5992*	
	28	5992	12.29
(VI)	*70*	*1398*	
	70	1398	0.00
(VII)	*75*	*1020*	
	73	1000	2.12
	509	20	1.95
(VIII)	*76*	*3494*	
	34	383	18.75
	36	931	17.70
	75	1200	0.70
	80	500	11.32
	509	480	2.65
(IX)	*97*	*2431*	
	70	2431	6.74
(X)	*122*	*7604*	
	104	2700	9.80
	119	2000	0.82
	132	1500	6.35
	133	1404	3.76
(XI)	*138*	*54*	
	148	54	7.40
(XII)	*150*	*6102*	
	133	596	3.83
	144	4000	4.79
	150	1000	0.00

(continued)

Table 5 (continued)

S No.	Cluster 1 (O-D)	Allocated evacuees	Distance (km)
	151	506	11.02
(XIII)	*353*	*6*	
	353	6	0.00
(XIV)	*365*	*9619*	
	70	1071	8.41
	83	2200	5.91
	95	2700	7.61
	97	1000	1.68
	102	500	7.14
	113	148	11.41
	365	1000	0.00
	531	1000	9.68
	Grand total	43,704	

the framework can be extended to study many hazard scenarios to identify long-term and short-term strategies for planning locations of permanent shelters, relief supplies, hospitals and resource personnel for effective and efficient disaster response.

Table 6 Cluster 2 node origins and destinations with allocated evacuees and distance

S No.	Cluster 2 (O-D)	Allocated evacuees	Distance (km)
(I)	*2*	*1742*	
	1	1543	3.34
	2	199	0.00
(II)	*3*	*2943*	
	3	300	0.00
	6	853	9.72
	7	500	13.97
	13	1290	6.45
(III)	*6*	*420*	
	2	273	3.73
	6	147	0.00
(IV)	*19*	*5060*	
	4	4150	17.74
	13	910	18.57
(V)	*20*	*8022*	
	2	2028	30.30
	11	500	19.12
	15	2500	20.54
	19	1200	4.72
	20	606	0.00
	353	1188	9.15
(VI)	*26*	*274*	
	26	274	0.00
(VII)	*28*	*693*	
	20	693	8.34
(VIII)	*36*	*1699*	
	26	926	6.65
	34	773	1.05
(IX)	*53*	*3558*	
	21	500	26.13
	30	314	43.25
	34	1244	18.39
	39	500	21.18
	65	500	27.18
	356	500	22.84
(X)	*56*	*425*	

(continued)

Table 6 (continued)

S No.	Cluster 2 (O-D)	Allocated evacuees	Distance (km)
	33	425	40.28
(XI)	*70*	*1441*	
	111	1000	17.80
	113	441	14.40
(XII)	*73*	*1583*	
	33	381	35.63
	142	420	34.22
	174	782	42.42
(XIII)	*76*	*202*	
	142	202	37.04
(XIV)	*77*	*8350*	
	77	2200	0.00
	99	3200	5.81
	113	2411	16.72
	127	346	35.39
	151	134	32.02
	175	59	34.08
(XV)	*83*	*4654*	
	127	4654	30.63
(XVI)	*94*	*3380*	
	30	186	47.56
	33	194	42.41
	35	1500	49.16
	101	500	39.39
	106	500	43.61
	107	500	44.04
(XVII)	*130*	*887*	
	143	887	18.83
(XVIII)	*133*	*28*	
	175	28	15.15
(XIX)	*138*	*5*	
	148	5	7.40
(XX)	*150*	*6673*	
	143	1613	15.63
	151	2360	11.02
	152	2700	17.83

(continued)

Table 6 (continued)

S No.	Cluster 2 (O-D)	Allocated evacuees	Distance (km)
(XXI)	*163*	*3413*	
	175	3413	1.82
(XXII)	*509*	*1878*	
	142	1878	38.28
	Total	57,330	

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Climate Change Adaptation and Mapping Tools

Assessment of Socio-economic Impact of Urban Flooding in Hyderabad Due to Climate Change

Md. Abdul Jabbar Sharief and Bharadwaj Vangipuram

Abstract Cities are urbanising at a rapid rate to accommodate the inflow of population who come for better opportunities and life. According to the United Nations Development Programme, about half of the world's population lives in cities and is estimated that by 2050 three quarters will live in cities. In countries like India, the centralisation of opportunities and quality of life in cities had started the trend of people migrating to cities. There are many factors that contribute to the flooding of Indian cities. Human intervention has only amplified the situation. People most prone to be affected by flooding in cities are people living near river basins, catchment areas of lakes and encroachments over water bodies. Maintenance of the system of stormwater drains also plays a huge role in determining the areas that are inundated in a city. Considering the vast scope of the study, Hyderabad, the capital city of Telangana which faced the wrath of unseasonal rains resulting in flooding of the Musi river and inundation of few areas in October 2020. This city has been considered for the study of the socio-economic impacts of urban flooding. Data on rainfall from literature review of various papers have concluded that average unseasonal rainfall has been increasing over the years since 1905. Considering this uptrend of rainfall, using Representative Concentration Path (RCP) future rainfall data is predicted till the year 2100 using literature review. The study of socio-economic factors includes the per capita income of people, the extent of disruption of economic activity, supply chain disruption and the possibility of people being pushed into poverty again. Analysing these factors will help future policymaking and mitigation efforts which will help in reduction of damages caused by urban flooding.

Keywords Urban flooding · Migration · Global climate model · Representative concentration path · Policymaking · Mitigation

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1 Introduction

1.1 Background

South Asia has always been susceptible to flooding during monsoon and unseasonal rains. The frequency of flooding has tripled and the corresponding economic and loss of human lives have increased by more than five-fold in the last three decades [1]. Moreover, Indian cities, which have been struggling to endure with ailing infrastructure, are not able to cope up with increasing urbanisation. There is an uptrend of rural population migrating to cities for better opportunities and quality of life. Indian cities are densely populated and migrating populations from rural areas are causing stress on city's infrastructure. The reverse trend of people migrating from city to villages is insignificant, thus causing cities unable to handle the migrating population [2].

Flooding is a phenomenon where there is an interruption to the natural flow of water or immense rainfall which the existing stormwater drains cannot control. The rapid urbanisation of Indian cities has led to both obstructions of the natural flow and water flow into existing stormwater drains that are immense that it is unable to handle. The increasing urbanisation of Indian cities has escalated the flood peaks from 1.6 to eight times and flood volume up to six times. This increases the economic losses and human causalities [3].

1.2 Flooding in Indian Cities

Indian cities have been facing the fury of floods which can be attributed to various reasons. Enumerating the floods in Hyderabad in 2000, Ahmedabad in 2001, Delhi 2002 and 2003, Chennai in 2004, Mumbai in 2005, Surat in 2006, Kolkata in 2007, Jamshedpur in 2008, Delhi in 2009, Guwahati and Delhi in 2010, Srinagar in 2014, Chennai in 2015, Gurugram in 2016, Hyderabad in 2020. Furthermore, a series of floods affected the entire states of Kerala, Karnataka and Gujarat in 2018 and 2019 respectively. Analysing the causes for the floods in urban areas, the causes can be categorised into river floods, flash floods (generally caused by the failure of reservoir or dam on the upstream side), poor stormwater drain infrastructure, encroachments over natural catchment areas.

Urban flooding in India is a persistent problem due to which there are predicaments in terms of economic losses and vulnerability to communities living in flood-prone areas. The economic losses due to urban flooding in India account for the range of 1.1$ billion to 5$ billion a year [3]. The losses do not account for the impact of these floods on informal settlements like slums which reside in flood-prone areas and small businesses in these localities which are subjected to the vulnerability of shutting down their respective business.

1.3 Impact of Climate Change and Urbanisation on Flooding

The haphazard growth of a city can lead to improper city planning leading to blocking the natural flow of water and irregular water management infrastructure. This exponential growth along with climate change has caused havoc in Indian cities in the form of floods.

The study was conducted in Hyderabad, the capital city of Telangana. The impact of climate change on rainfall and urbanisation during the period of flood along with corresponding economic damages caused during the years 1908, 2000, 2008, 2020 are enumerated in Table 1 and Fig. 1. Although the amount of rainfall in 1908 was more than in the other years, the economic damages caused in recent years have been increasing with each flood. The urbanisation of the city has been rapidly increasing over years resulting in mounting economic losses.

Table 1 Urban flood events in Hyderabad [4–6]

Rainfall event	28/29th February 1908	23/24 August 2000	8/9/10 August 2008	13/14 October 2020
Rainfall magnitude	430 mm	240 mm	237 mm	241 mm
Loss property	₹ 10 Million	₹ 10.35 Million	₹ 4.9 Million	₹ 6.7 Billion
Loss of life	1500	26	39	36

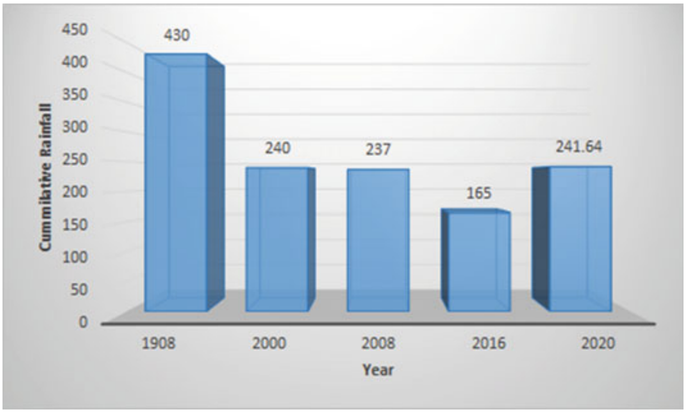

Fig. 1 The cumulative rainfall of years 1908, 2000, 2008,2016 and 2020 are compared for their magnitude (Compiled from Indian Meteorological Department)

2 Methodology

The study aims at analysing the socio-economic impacts of urban flooding in Indian cities for which Hyderabad city was chosen as the study area. The study was conducted in three phases which are outlined below:

1. Rainfall data of 120 years of Hyderabad city was collected which would help in analysing the frequency of flooding and intensity of rainfall for corresponding floods. Literature review based on Representative Concentration Path which could predict the intensity of rainfall for coming 100 years.
2. Using the available data on Hyderabad city, ArcGIS was used to represent the areas and water bodies that cause flooding in nearby areas. A survey was conducted in areas that were inundated during the 2020 Hyderabad floods. The areas to be surveyed were chosen based on different types of urban flooding, which will widen the perspective on urban flooding' effects.
3. The survey involved interviewing people affected during the floods and collecting parameters such as income range, damage caused, compensation, government schemes usage among many to identify the effects of urban floods. Data collected in the survey is used to analyse the socio-economic impacts of flooding in Hyderabad city. The generalised impact of urban flooding for other cities is discussed based on collected parameters during the survey.

2.1 Study Area

The study has been conducted in Hyderabad city, which is capital of Telangana state in India. Hyderabad city was chosen for the current study as it has faced flooding in recent years as highlighted in the previous section. Musi, a tributary of river Krishna flows through the city. Moreover, the city has many artificial water bodies such as Hussain Sagar and natural water bodies which make it easy for the study to generalise the impact of urban flooding to other Indian cities which have a similar case of river flowing through the city and natural water bodies (Fig. 2).

2.2 Climate Change and Rainfall

Analysing the rainfall data of Hyderabad for the last 120 years reveals that the recurrence of intense rainfall has increased in the last four decades. The normal annual rainfall as given by Indian Meteorological Department for Hyderabad is 845.6 mm and in last four decades, the cumulative rainfall in Hyderabad has exceeded 1000 mm several times. From Fig. 3, it can be observed that intensity of rainfall has been increasing during the last few decades. Since the last 120 years, Hyderabad has recorded its highest rainfall of 1331.37 mm in 2020.

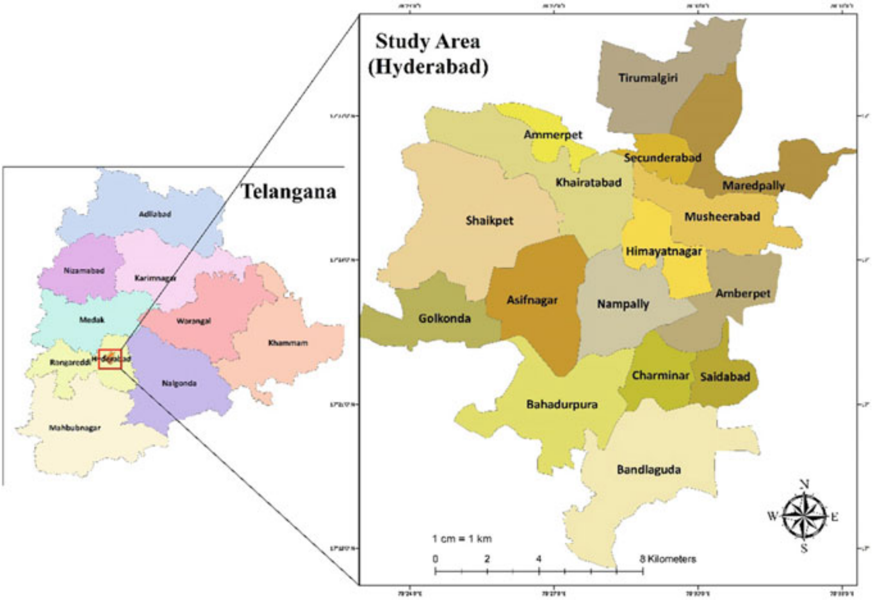

Fig. 2 The representation of Hyderabad in Telangana and zones in Hyderabad using ArcGIS

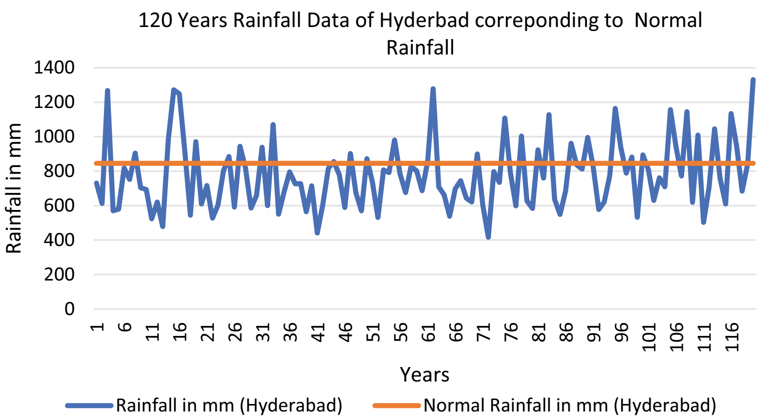

Fig. 3. 120 years cumulative rainfall data of Hyderabad compared with normal rainfall (Compiled from IMD)

Considering both the scenarios of Representative Concentration Pathways of 6.0 and 8.5. The models analysed for historic rainfall and calculated rainfall with RCP 6.0 and 8.5, RCP 8.5 was accurate with its peak rainfall in the year 2083. The RCP 6.0 overestimates the rainfall intensity as observed when compared with historic rainfall of Hyderabad [5].

As observed from Table 2, the intensity of daily rainfall will increase till 2084–2093 and reduce in consequent years. With rainfall intensity and urbanisation, the economic damage that was caused in 2020 Hyderabad floods was about ₹ 6.7 billion. The increasing rainfall intensity along with rapid urbanisation tends to cause more damages in terms of human lives and economic loss.

2.3 Survey and Data Collection

A survey was conducted for assessment of socio-economic impact of the 2020 floods in Hyderabad. The survey was divided into two phases, first, one aimed at evaluating the parameters for residential houses and second one was to assess the impact of floods on economic activity in the same area. Primarily, to conduct the survey, areas were chosen based on the source and type of flooding. As mentioned in previous section that urban flooding is caused by various reasons. Based on various types, areas were chosen for survey (Fig. 4).

- Moosarambagh was selected for survey owing to the fact that the flooding was caused by Musi river which passes through the area. Musi experienced a maximum flood level of about 9 feet during the floods in that area. This led to inundation of areas near the Musi river.
- Chandrayangutta was one of the most affected floods in Hyderabad. Primarily, the area was flooded due to breach and overflow of water from nearby Gurram Cherruvu Lake and improper functioning of stormwater drains.
- Yakuthpura was flooded due to multiple reasons. The nearby Balapur lake was breached and Musi was flooded due to release of water from Himayat Sagar. The area is low lying which resulted in inundation of the area by about 9 feet.
- Kavadiguda was flooded due to water mismanagement. The improper functioning of stormwater drains led to stagnation of water in the area. Although the area was flooded, the intensity of flooding was mild when compared to other areas of the present study.

The survey included the income of an individual or family, losses due to floods, financial aid provided by government, utilisation of government schemes and real estate after flooding. The economic activity survey included gross income of the business, loss due to floods, capital required to restart the business, extent of supply chain disruption.

3 Result and Discussion

The data collected during the survey enable the study to analyse the income groups which were vulnerable to urban flooding. People from each area were interviewed for the details, around 100 people were interviewed in each area during the survey (Table 3; Fig. 5).

Table 2 Maximum daily rainfall intensity in Hyderabad predicted using RCP 8.5 [5]

	2017–2027	2028–2038	2039–2049	2050–2060	2061–2071	2072–2082	2084–2093	2094–2100
RCP 8.5	150 mm	120–130 mm	190–200 mm	140–150 mm	280–290 mm	300–310 mm	540–550 mm	250–260 mm

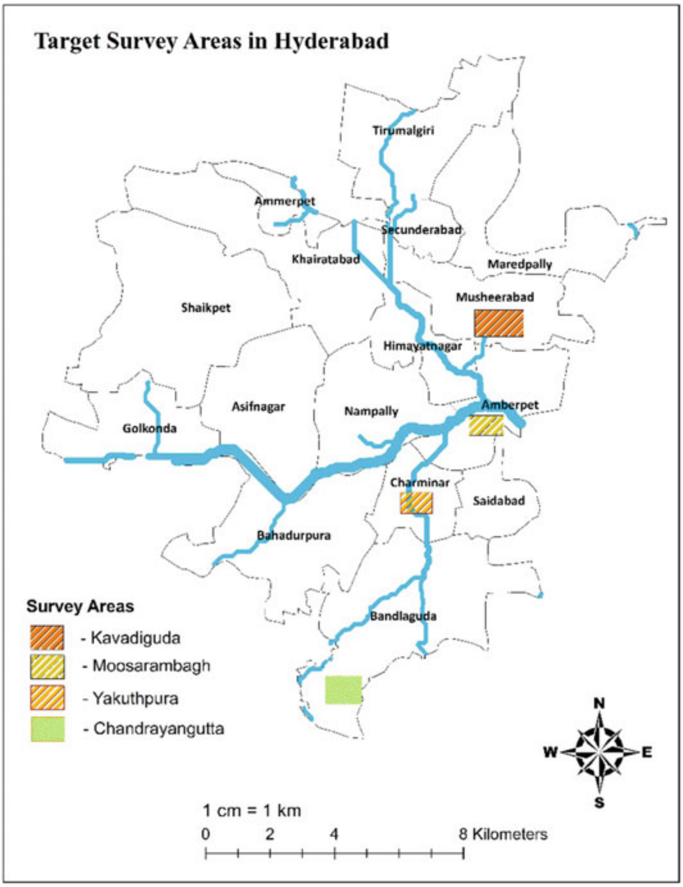

Fig. 4 Surveyed area along with water bodies near the corresponding areas

Residential houses with more than one storey were mostly damaged on the first storey and higher storeys were unaffected. But vehicles owned by higher storey people were damaged or washed away by the floods. The damages mentioned in Table 4 does not account for vehicular damages but only accounts for property, valuables damaged partly or fully by the flooding. The astonishing data on real estate in the areas which were flooded did not drop due to flooding but flourished with the same prices for rental and sale.

The shops in the areas were also affected by the flooding. The shops are mostly small-scale neighbourhood retail shops and repair shops. Apart from this the areas also had other retail activity which was generally community/neighbourhood shops such as ironing shops, small-scale fast-food joints. Most of the shops were on the ground floor of buildings which led to complete inundation in all the areas except Kavadiguda. Kavadiguda experienced waterlogging, thus shops were not completely damaged (Fig. 6).

Table 3 Survey data collected from residential houses in listed areas

Area Income range of individual /business	Kavadiguda	Moosarambagh	Yakuthpura	Chandrayangutta
Below poverty line	0	120	20	4
Poor	40	10	45	78
low-income Group	57	30	20	40
Medium income group	31	7	15	3
Higher medium income group	27	2	0	0
Total	155	179	100	125

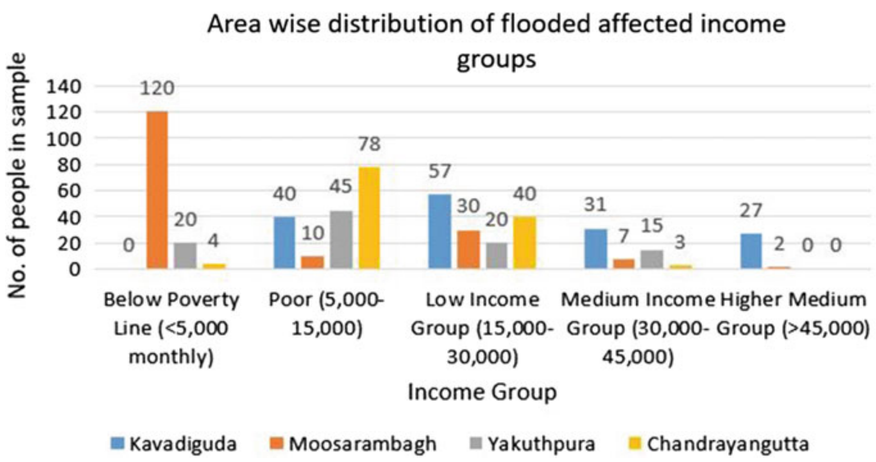

Fig. 5 Income ranges of people affected by floods in areas where survey was conducted

Table 4 Loss due floods in surveyed areas for residential houses

Range of loss/damage	<one lakh	1.5–2 lakhs	No loss
No. of people	300	200	201

The shops which are the economic activity in the flooded areas which were surveyed were completely inundated which resulted in damaging the stock in the shops. During the floods, the shops which were functional were not able to access essential commodities such as milk and vegetables among many. The supply chain during the period of flooding was completely disrupted leading to a shortage of essential commodities. The loss incurred by the shops in the areas were in the range of 2.5–3 lakh rupees. More than the damage caused, owners of the shops were facing trouble in restarting their business as they were short of capital.

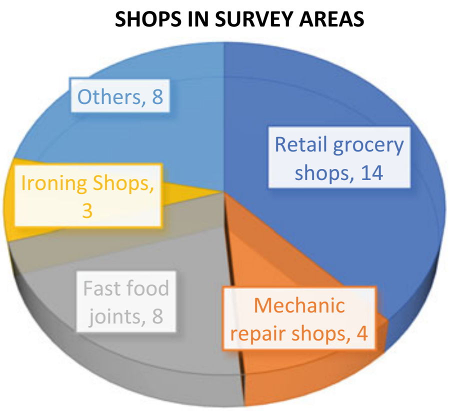

Fig. 6 Various types of shops in flooded areas which were surveyed

The capital for restarting business has become a hurdle for local shop owners. Due to flooding, the business has slowed down which has resulted in a few shops shutting down.

4 Conclusions

The analysis of the survey conducted in flood-affected areas of Hyderabad indicated that a set of income range people were affected more than other income ranges. The poor and low-income group sections are more affected by the flooding than other income ranges of the corresponding flood surveyed areas. The damage or loss that were incurred during the flooding caused substantial stress in those income groups. The financial aid provided by the government for loss incurred during flood is insufficient to suffice the loss caused by it.

Those income groups are vulnerable to being pushed back into poverty. During the last two decades, India has successfully helped millions alleviate poverty. The poverty was alleviated by opportunities in terms of business opportunities or jobs, but urban flooding has become a hurdle in creating more opportunities. These floods have caused damage pushing the progress of few people back by few decades.

The present study was limited to Hyderabad for conducting socio-economic impact of urban flooding due to vast scope of the study. Many Indian cities are vulnerable to flooding which are resulting in massive economic losses and pushes people into poverty. It is predicted that will have 20 metropolitan cities by the end of the next decade. Climate change and urbanisation will have an impact on flooding in cities resulting in hindering the development and upliftment of people.

The present study highlighted the vulnerable sections of people who will be affected by floods. Mitigation measures must be planned by authorities to avoid loss of property and human life. If measures are not taken to curb the damages future rainfalls will have repercussions in terms of poverty, opportunity and functioning of businesses. Water management in cities must be strengthened in order to avoid future inundations. This will partly ensure sustainable cities & communities, no poverty and climate change goals are achieved as set by United Nations Development Program.

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Application of ArcGIS and HEC-RAS in Assessing Sedimentation in Godavari River Reach

S. Kiran, Anwesna Poudyal, Samer Pradhan, and Monalisha Gautom

Abstract Assessment of sediment load is paramount in understanding the process of erosion and deposition in rivers. Excess sedimentation is hazardous as it reduces the carrying capacity of the river and destabilizes the channel banks. In this study, the transport model in Hydrologic Engineering Centre's River Analysis System (HEC-RAS) is coupled with quasi-unsteady flow series to quantify the sediment discharge and assess erosion and deposition at each cross section along the Godavari River reach. The topography of the river reach is extracted and digitized using HEC-GeoRAS tool in ArcGIS. To accurately reproduce the natural hydraulic behaviour in the river reach, the cross-sectional lines are positioned at optimal spacing and approximately perpendicular to the direction of river flow. The Manning's roughness coefficient (n) is calibrated using one-dimensional unsteady flow model in HEC-RAS. The unsteady model computes the hydraulic properties and provides simultaneous solutions for discharge and stage at each computational time step for all cross sections. The sediment continuity equation is solved for non-equilibrium sediment transport over the control volume along with the hydraulic sorting and armouring. Results from the simulated models are compared and calibrated against observed field measurements. Weighted coefficient of determination (ωr^2), Nash–Sutcliffe efficiency (E), modified Nash–Sutcliffe efficiency (E_1) and Modified index of agreement (d_1) are used to provide an objective assessment about the closeness between the simulated and observed values. Among the transport models in HEC-RAS, the Wilcock-Crowe model provides more accurate estimates of sediment discharge and deposition and erosion at each cross section along river reach.

Keywords Sediment transport · Godavari river · ArcGIS · HEC-RAS · Wilcock-crowe

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1 Introduction

Influx of excess sediment impacts erosion and aggradation in dynamic rivers and modifies the channel characteristics altering the river's morphology. Extreme climatic conditions, nature of topography, land use pattern and terrain slope are few among the several natural factors that enhance the rate of sediment yield in a river. Unsustainable farming techniques and inadequate watershed management have also contributed to an increase in the influx of sediment load. Excess sedimentation is hazardous as it reduces the carrying capacity of the river and destabilizes the channel banks. Assessment of sediment load in rivers is paramount in understanding the process of erosion and deposition. It will also provide vital information required in planning, designing and managing water resource systems.

Godavari River originates in the Western Ghats and flows eastwards across the Deccan plateau into Bay of Bengal. The study reach extends from Peruru to Polavaram which is approximately 268 km in distance. Width of the channel in the study reach varies from 700 m at its narrowest to 3000 m at its widest sections. Due to its high erosion rate, which differs from one part of the basin to another, Godavari River is characterized by excessive sediment discharge. Almost 95% of the sediment load in Godavari River is predominantly monsoonal or transported during the wet season [1].

Several studies have been carried out to simulate the sediment transport process in natural flows. The hydraulic characteristics of the channel are emulated in the model through Manning's roughness coefficient. Stability of finite difference scheme is influenced by the weighting factor and computational time step during calibration of Manning's roughness coefficient [2]. Though sediment transport is unsteady, most formulae have limited applicability and can be used only to evaluate the transport capacity in steady uniform flows. To overcome this limitation, one-dimensional sediment transport algorithms adopted the quasi-unsteady approach. A comparison between the unsteady and quasi-unsteady sediment transport models indicated that the unsteady model made no significant improvement in accuracy over the quasi-unsteady model [3]. The quasi-unsteady transport model provided approximate results for erosion and deposition in meandering channels, assuming equilibrium between the volumetric sediment discharge and transport capacity [4]. However, it is unlikely and unrealistic to assume the flux in the system to be in equilibrium as the process of sediment transport is often complex and imbalanced. For a credible model assessment, the combination of different efficiency measures should be consistent. The sensitivity in each efficiency criteria has to be considered before application. The over and under predictions are to be reflected along with other attributes of transport, providing a more comprehensive evaluation of model results [5].

With the advancement in technology, simulation of sediment transport using sophisticated algorithms has enabled robust modelling and prediction of the sediment dynamics in river systems. For this process, several modelling packages like FLUENT, CFX, PHOENIX, FLUIVAL, MIKE 21, CCHE2D, CCHE1D and HEC-RAS are used. In this study, the hybrid one-dimensional HEC-RAS (version 5.0.7) model developed by Hydrologic Engineering Centre of the US Army Corps of Engineers is considered [6]. Among the four river analysis components in HEC-RAS, the unsteady flow condition is used in calibrating Manning's roughness coefficient and the quasi-unsteady sediment transport model is used in determining the sediment discharge in the river reach.

2 Methodology

2.1 Geometry

The geometric data which includes the river path, cross section, flow lines and bank stations are extracted from the digital elevation model (DEM) having a spatial resolution of 1- arc second. DEM is obtained from the satellite images of Shuttle Radar Topography Mission (SRTM) by the U.S. Geological Survey (USGS). The reach of Godavari River between Perur and Polavaram (refer Fig. 1 and Table 1) is digitized in ArcGIS.

To accurately depict the hydraulic conditions in the river reach, the cross-sectional lines are approximately perpendicular to the direction of flow. The optimum spacing

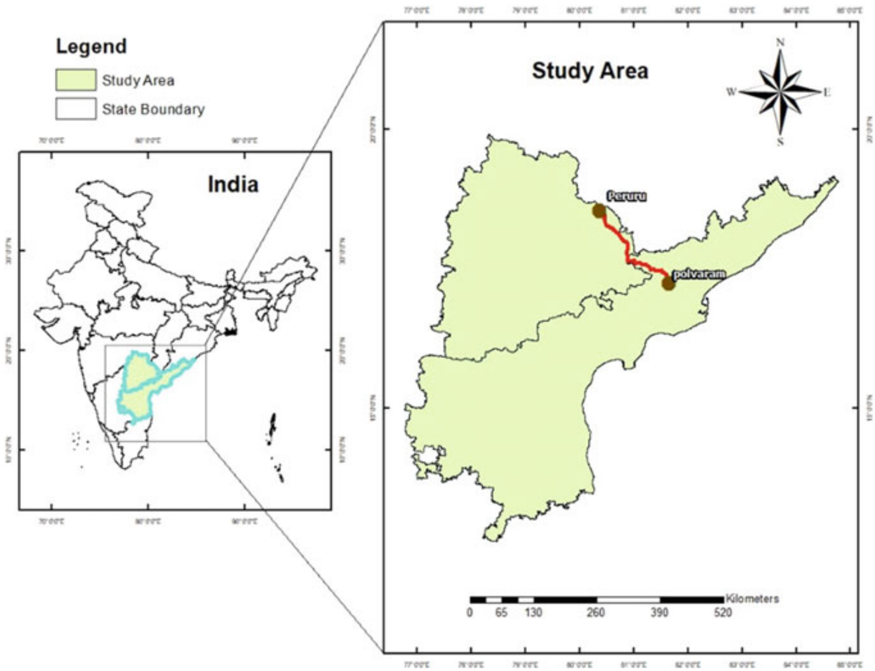

Fig. 1 Location of study area

Table 1 Location of upstream and downstream boundary stations

Station	Latitude	Longitude	Boundary
Perur	18° 33′ 00″	80° 22′ 00″	Upstream
Polavaram	17° 14′ 45″	81° 39′ 35″	Downstream

between the cross-sectional lines is proportional to bankfull surface width of the channel. The inclusion of additional cross sections may not necessarily increase the model accuracy once the optimal spacing is attained [7]. The river reaches in this study has been divided into 105 cross sections with an average distance of 2.5 km between each cross section as shown in Fig. 2. HEC-GeoRAS extension in ArcGIS is used to create the geometry file and export it into HEC-RAS where bank stations at each cross section are adjusted to bankfull depth manually.

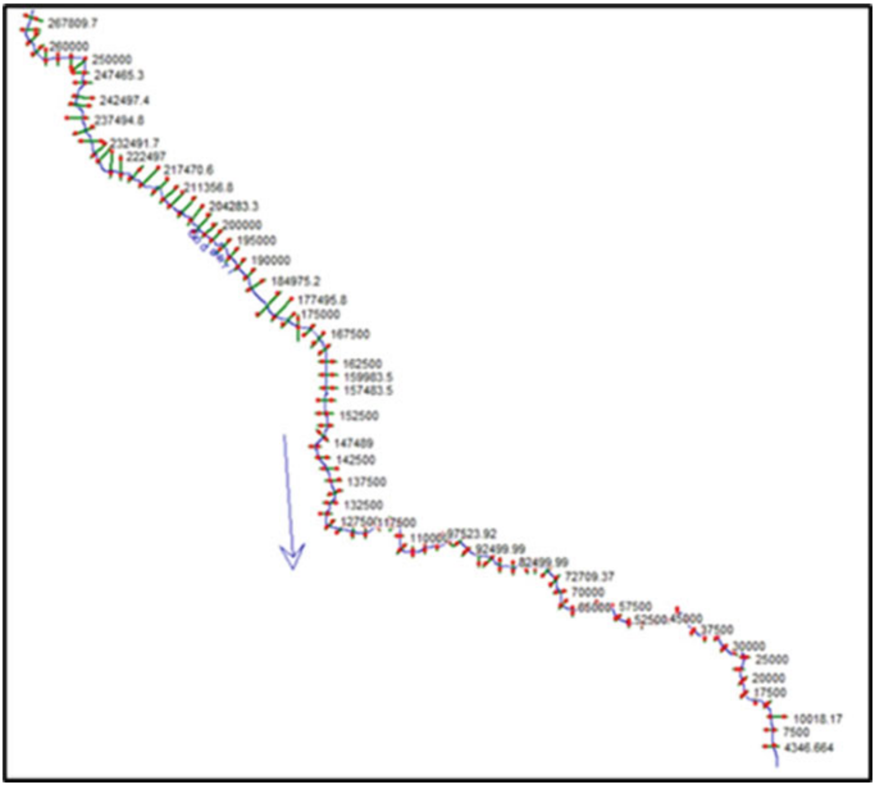

Fig. 2 Study reach of Godavari River between Perur and Polavaram

2.2 One-Dimensional Unsteady Flow Model

The Manning's roughness coefficient is calibrated using the one-dimensional unsteady flow model. The governing equation for one-dimensional unsteady flow in HEC-RAS is the Saint Venant equation which comprises the continuity equation (Eq. 1) and momentum equation (Eq. 2) solved using the four-point implicit scheme. The model computes the hydraulic properties to provide simultaneous solutions for discharge and stage at each computational time step for all cross sections.

$$\frac{\partial A}{\partial t} + \frac{\partial Q}{\partial x} - q = 0 \quad (1)$$

$$\frac{\partial Q}{\partial t} + \frac{\partial (QV)}{\partial x} + gA\left(\frac{\partial z}{\partial x} + S_f\right) = 0 \quad (2)$$

where A is the cross-sectional flow area, Q is the flow discharge, q is the lateral inflow per unit length, V is the velocity of flow, z is the water surface elevation and S_f is friction slope.

Stability of the unsteady flow model in HEC-RAS depends upon the computational intervals chosen. At large time steps, certain peak flows in the inflow hydrograph might be missed at some cross sections. Continuous monitoring of inflow hydrograph, to identify the change in flow rate from one time step to another, improves the stability of the unsteady flow model.

2.3 Sediment Transport Model

In HEC-RAS the Exner's equation (Eq. 3) is used to route sediment continuity wherein it computes the difference between the inflowing and outflowing sediment load in a control volume.

$$\left(1 - \lambda_p\right)B\frac{\partial \eta}{\partial t} = -\frac{\partial Q_s}{\partial x} \quad (3)$$

where, λ_p is the porosity of bed surface layer, B is the channel width, η bed surface elevation and Q_s is the transported sediment load.

If the transport capacity of the control volume is lesser than the inflowing sediment supply, the surplus sediment load is stored in the bed surface layer as a multiphase sediment–water mixture, causing sediment deposition. The deficit is removed from the control volume if the transport capacity exceeds the inflowing sediment supply, resulting in sediment erosion. The change in the elevation of the bed surface layer is indicated by the porosity of the multiphase mixture [8]. In HEC-RAS, the sediment transport potential of the control volume is computed independently for each grain class using empirical sediment transport algorithms that translate the hydrodynamic conditions at each cross section into transport. The total transport capacity is computed by assessing the proportion of all grain classes involved in the transport [9].

The boundary condition at upstream cross section is the quasi-unsteady inflow hydrograph. In a quasi-unsteady condition, the continuous inflow hydrograph is transformed into a series of discrete intervals consisting of steady flow profiles over the flow duration. Sediment transport computations in HEC-RAS assume no change occurs in the elevation of the bed surface layer over a computational time step. The 24-h flow duration is further subdivided into variable computational intervals to reduce model instability as higher flows tend to increase the change in bed surface elevation. The boundary condition at the downstream cross section is the normal depth which requires the channel slope to be given as input. The slope of the river reach between Perur and Polavaram is calculated from the profile of the geometry in HEC-RAS. The mean diameters of the bed sediment particles are obtained from samples collected along various points in the river bed. The bed sediment gradations are first defined in a database and then assigned to the upstream and downstream cross sections respectively. For intermediate cross sections, the bed gradations are interpolated from the samples. The mean diameters of the bed material at Perur and Polavaram are 1.31 mm and 1.09 mm respectively. The sediment flow characteristics are defined using a rating curve consisting of five flow-load points encompassing the entire range of flow. The erodible limits are set within the bank extents. Unlike the equilibrium load condition where sediment discharge is equated to its transport capacity in a control volume, non-equilibrium transport model computes the boundary sediment load based on inflow hydrograph and sample load points.

3 Results and Discussion

3.1 Calibration of Manning's Roughness Coefficient (N)

The inflow hydrograph, from 1st September 2017 to 31st October 2017, defined at the upstream boundary is continuously monitored for large changes inflows. The computational intervals are adjusted when the difference in flow rate between time steps exceeds the critical value. The Manning's roughness coefficient (n) is calibrated by simulating the unsteady flow model for different values of n along the cross section. To evaluate the performance of the hydraulic model, simulated discharge values are compared with observed measurements at Polavaram station (refer Fig. 3). Weighted coefficient of determination $\left(\omega r^2\right)$, Nash–Sutcliffe efficiency (E), modified Nash–Sutcliffe efficiency (E_1) and Modified index of agreement (d_1) are considered to provide an objective assessment of how well a simulated model fits the recorded observations for different values of Manning's coefficient. HydroGOF function in R

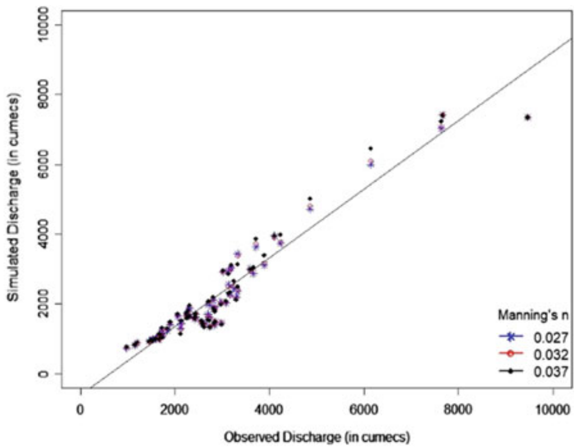

Fig. 3 Observed and simulated discharge for different Manning's roughness coefficient (n) values at Polavaram station

Table 2 Efficiency criteria for different values of manning's roughness coefficient (n)

Manning's roughness coefficient (n)	ωr^2	E	E_1	d_1
0.027	0.749	0.723	0.278	0.705
0.032	0.753	0.727	0.295	0.714
0.037	0.752	0.728	0.298	0.715

is used in the estimation of efficiency measures. The most appropriate value of n is selected based on these efficiency measures.

From the results presented Table 2 and Fig. 2, it can be observed that Manning's roughness coefficient of 0.037 has the best values for E, E_1 and d_1. Hence, 0.037 is chosen as the final calibrated value of n for sediment analysis.

3.2 *Sediment Transport Function*

To compute the total transport capacity, the model is simulated for the entire flow duration combining various sediment transport functions with armouring techniques and fall velocities. It involves routing of sediment at cross sections considering the sediment dynamics. The simulated sediment discharge at Polavaram station is compared with the recorded observations to select the most suitable transport function. The performance of various sediment transport models is summarized in Table 3.

It is crucial to identify transport functions that define sediment transport accurately. For evaluation of model performance based on ωr^2, information about the gradient integrated into its calculation is also considered. Gradient values closer to one indicate good agreement. The Wilcock-Crowe transport function had a gradient

Table 3 Efficiency criteria indicating model performance with different sediment transport functions

Transport function	Sorting method	ωr^2	E	E_1	d_1
Acker's White	Thomas (Ex 5)	0.264	0.237	−0.004	0.533
Engelund-Hansen	Thomas (Ex 5)	0.476	0.576	0.168	0.620
	Active Layer	0.466	0.561	0.161	0.615
Laursen (Copeland)	Thomas (Ex 5)	0.326	0.341	0.138	0.576
Tofaleti	Thomas (Ex 5)	0.173	−0.021	−0.147	0.476
Meyer Peter Muller	Thomas (Ex 5)	0.252	0.200	0.007	0.532
Wilcock-Crowe	Active Layer	0.585	0.736	0.365	0.699
MPM- Tofaleti	Thomas (Ex 5)	0.227	0.112	−0.060	0.507
Yang	Active Layer	0.358	0.412	0.153	0.587

of 0.675 which was higher than the other gradients and also produced the best result of 0.585 for ωr^2.

E values closer to one indicate good correlation and for lower values E_1 the model performance is interpreted as poor. Efficiency criteria lesser than zero indicates the mean of the observed time series would produce better predictions than the model. From Table 3, it is observed that there is poor agreement between the modelled and observed hydraulic behaviour when Tofaleti, MPM-Tofaleti and Acker's White transport functions are considered. The values of E and E_1 for Tofaleti,E_1 for MPM-Tofaleti and Acker's White are all less than zero indicating poor model performance. The Wilcock-Crowe function gave the best values for $E(0.736)$ and $E_1(0.365)$ amongst the functions considered in this study. It also has the best value of 0.699 for d_1 (Value of 1 implies perfect fit). The sediment discharge at Polavaram, computed using the Wilcock-Crowe transport function, is compared with the recorded observations at the station (refer Fig. 4).

The efficiency measures produced more accurate and consistent results for the Wilcock-Crowe transport function. It is therefore used in computing the erosion and aggradation at each cross section along the river reach.

3.3 Predication of Mean Effective Invert Change

The surplus or deficit sediment load at a cross section is transformed into equivalent values of depth, indicating aggradation or erosion at that section. The mean effective invert change provides the average change in bed elevation at a cross section after the flow duration. In sedimentation analysis, the mean effective channel invert provides a more realistic measure of erosion and deposition at station over the invert change which only considers the lowest point of elevation in a cross section at the end of simulation.

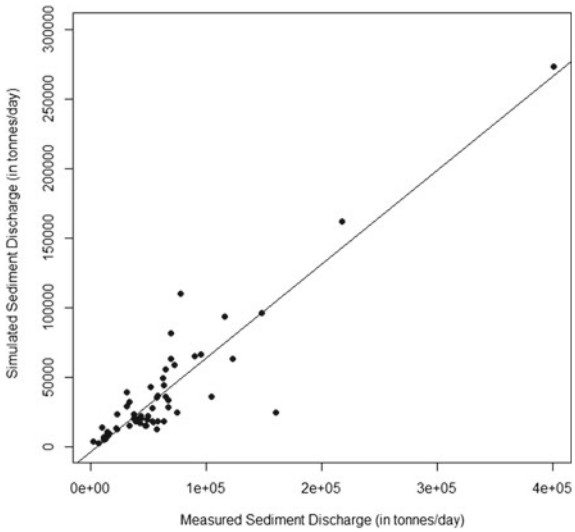

Fig. 4 Measured and simulated sediment discharge using Wilcock-Crowe transport function at Polavaram station

The bed elevation changes across 105 river stations, computed using the Wilcock-Crowe transport function, are shown in Fig. 5. The river stations are denoted from upstream to downstream. It is observed, at certain stations there is an alternating pattern of high erosion followed by deposition. These patterns could be consistently associated with abrupt changes in the relative elevation of the river's profile between successive cross sections. Significant erosion and deposition are observed in the river

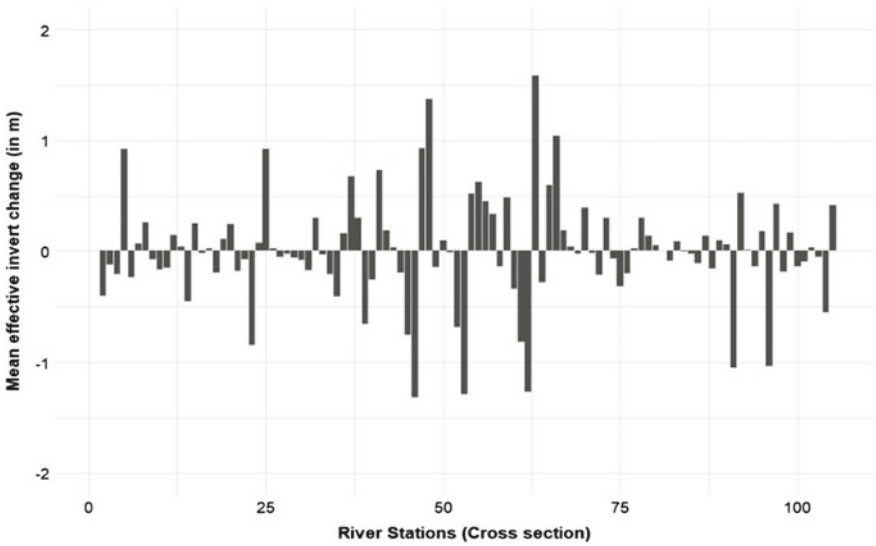

Fig. 5 Mean effective invert change across different cross sections

reach between stations 44 and 67 where the river reach undergoes a sharp change in its direction of flow. A gradual rise in erosion and deposition behaviour is also noted towards the end, between stations 90 and 97, where the river again changes its direction of flow. Maximum depth of erosion of 1.316 m is observed at river station 46. The deposition is maximum at the 63rd river station with a depth of 1.583 m.

4 Conclusion

In this study, we have considered the reach of Godavari River between Perur and Polavaram stations. Unsteady flow conditions were chosen over the conventional steady flow approach to determine Manning's roughness coefficient. To reproduce the natural hydraulic behaviour of the river reach, the model was calibrated by adjusting n values. Manning's roughness coefficient of 0.037 was selected based on the efficiency criteria.

Sedimentation along the river reach was computed using one-dimensional non-equilibrium sediment transport model. The most appropriate transport function was decided by calibrating the sediment discharge at downstream boundary. Values of ωr^2, E, E_1 and d_1 were comparatively higher for the Wilcock- Crowe transport function which provided a better estimation on sediment discharge in river reach between Perur and Polavaram. It should be noted that not all criteria will accurately quantify the model performance based on flow dynamics. Hence, it is imperative to choose criterion's that are positively correlated and provide a consistent assessment. The average change in bed elevation, depicted using the mean effective invert change, revealed that erosion and deposition in the river reach are influenced by both abrupt variations in the riverbed geometry and the change in direction of flow.

The maximum erosion and deposition were observed in these zones. It is noted that the accuracy of the model depends primarily on the quality of topographic data, hydraulic conditions in the river reach and the sediment transport function chosen. The characteristics of these empirical functions are to be compared with that of the flow scenario before incorporating it into the analysis. It is essential to understand and identify the limitations in each sediment transport function especially when they are associated with the modelling of sediment dynamics in natural flows.

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Decision Support Tool for Blast Mitigation

C. Murali Krishna and Tezeswi P. Tadepalli

Abstract In the current geopolitical scenario, it has become essential for urban planners to consider terrorism threats in the built environment. For emergency responders and law enforcement agencies, blast damage prediction is a critical requirement. A standalone and simple MATLAB-based Geographic Information System (GIS) tool for blast damage prediction has been developed, which assists planners to predict blast damage and primary blast mitigation efforts such as access control, standoff, and hardening of critical infrastructure. Various blast scenarios such as man-portable packages and automobiles are considered, and air blast effects modified for interaction with buildings are superimposed over an urban environment.

Keywords Blast · Mitigation · Emergency responders · Terrorism · Law enforcement agencies · MATLAB® · GIS

1 Introduction

In the current geopolitical scenario, terrorism threat has become essential for urban planners to consider in the built environment (Table 1). Improvised explosive devices (IEDs) can cause catastrophic damage to buildings, both externally and internally, leading to causalities. Preparedness for such threats and mitigating their effects is the most critical challenge for administrations and security agencies. Figure 1 shows the number of casualties in India due to various bomb sizes [1]. The data shows that the most significant number of deaths (fatalities and injuries) is due to car bombs.

This paper presents a simple tool for predicting the effects of air blast loads superimposed over urban terrain and environment, providing approximate estimates of the damage due to air blast in an urban environment while implementing public domain information.

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Table 1 Terrorist blasts in India state-wise incidents: 1998–2004 [1]

State	Number of fatalities	% of total fatalities	Number of incidents	% of total incidents
Andhra Pradesh	90	2.99	48	6.12
Arunachal Pradesh	1	0.03	1	0.13
Assam	376	12.5	85	10.84
Bihar	156	5.2	26	3.32
Chandigarh	0	0	1	0.13
Chhattisgarh	21	0.7	2	0.26
Delhi	25	0.83	14	1.79
Goa	0	0	1	0.13
Gujarat	2	0.07	8	1.02
Himachal Pradesh	46	1.53	4	0.51
Jammu and Kashmir	1658	55.11	480	61.22
Jharkhand	86	2.89	11	1.4
Karnataka	0	0	2	0.26
Kerala	0	0	3	0.38
Madhya Pradesh	22	0.74	1	0.13
Maharashtra	93	3.09	14	1.79
Manipur	94	3.12	17	2.17
Meghalaya	12	0.4	1	0.13
Mizoram	8	0.27	1	0.13
Nagaland	12	0.4	1	0.13
Orissa	7	0.23	3	0.38
Punjab	10	0.33	4	0.51
Tamil Nadu	72	2.39	18	2.3
Tripura	179	9.95	25	3.19
Unknown	2	0.07	3	0.38
Uttar Pradesh	23	0.76	4	0.51
Uttaranchal	2	0.07	1	0.13
West Bengal	11	0.37	5	0.64

2 Blast Effect Phenomena

The blast effects analysis was started in the twentieth century circa World War-II, which provided a plethora of blast data. An explosion with a high-pressure blast wave results in a rapid exothermic chemical reaction; as the reaction progresses, the explosive material either in solid or liquid form is converted into a hot, dense, high-pressure gas [3]. A high explosion causes shock waves at very high velocities to reach

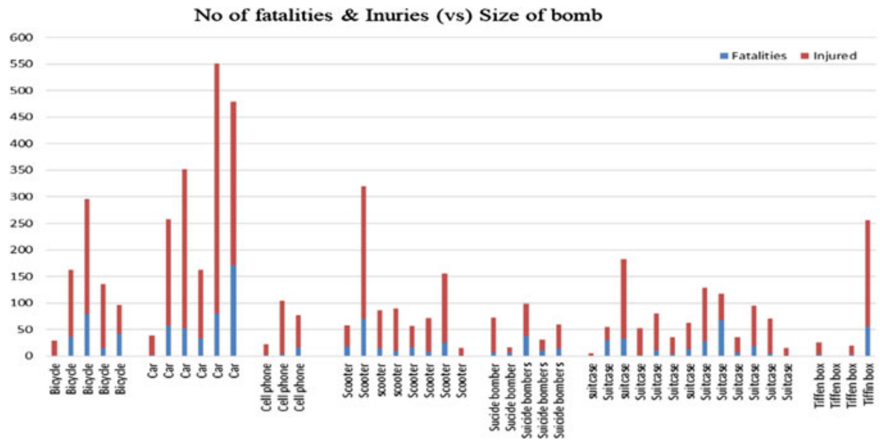

Fig. 1 Number of casualties versus size of the bomb [2]

equilibrium within the compressed air, traveling radially outward from the source at supersonic velocities. This initiates the process of blast shock wave propagation in the urban environment [4].

As the shock wavefront expands, pressure decays back to ambient pressure, a negative pressure phase, as shown in Fig. 2. The negative phase is usually neglected in design.

The blast pressures versus standoff distance graphs are typically available for free-field. However, the urban terrain offers multiple opportunities for the blast wave to be reflected, refracted, and focused. In this paper, the wavefront parameters produced by spherical explosives reported by Kinney and Graham [6] are modified based on street pressures and impulses enhanced by blast focusing [7]:

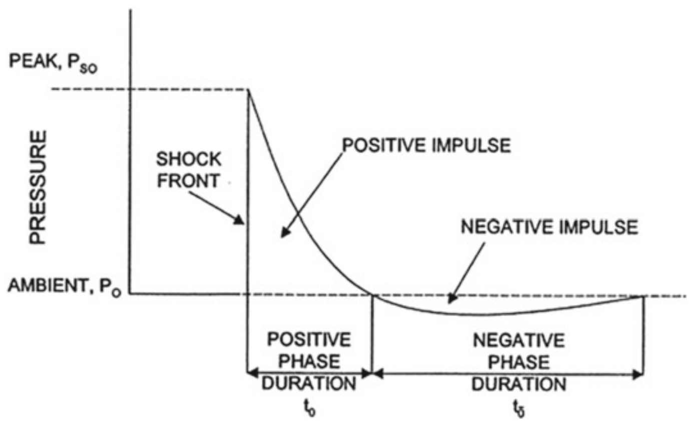

Fig. 2 Typical pressure–time history [5]

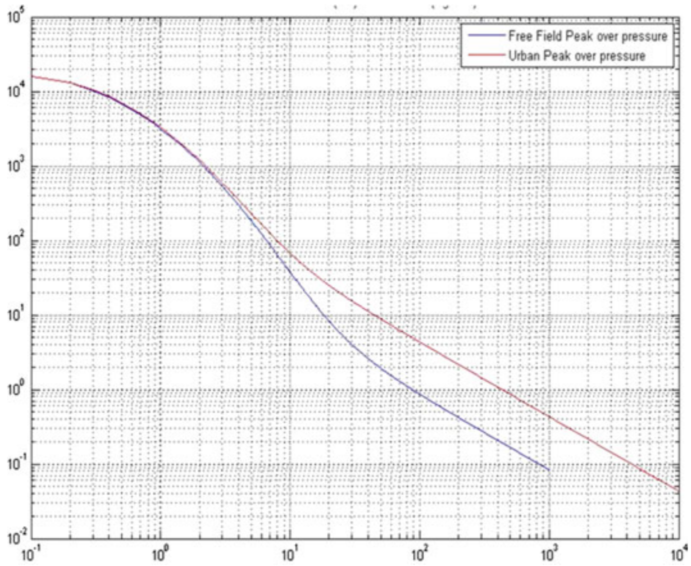

Fig. 3 Comparison of peak overpressure versus standoff [6, 7]

Peak pressure:

$$\frac{P_S}{P_O} = \frac{1200 \times 1 + \left(\frac{Z}{2}\right)^2}{\left\{\left[1 + \left(\frac{Z}{0.05}\right)^2\right] \times \left[1 + \left(\frac{Z}{0.315}\right)^2\right] \times \left[1 + \left(\frac{Z}{1.35}\right)^2\right]\right\}^{\frac{1}{2}}}$$

Time duration:

$$\frac{t_S}{W^{\frac{1}{3}}} = \frac{980 \times \left[1 + \left(\frac{Z}{0.54}\right)^{10}\right]}{\left\{\left[1 + \left(\frac{Z}{0.02}\right)^3\right] \times \left[1 + \left(\frac{Z}{0.75}\right)^6\right] \times \left[1 + \left(\frac{Z}{6.9}\right)^2\right]\right\}^{\frac{1}{2}}}$$

Impulse per unit area $= \frac{1}{2} \times P_s \times t_s$.

Figures 3 and 4 show the effect of urban terrain on the peak blast pressure and impulse.

3 Building Damage/Injury Criteria

The level of damage, i.e., the extent and severity due to an explosion, is uncertain and depends on several factors such as building geometry, construction type, etc., which may modify the blast effects. Past studies show that the unique specifics of a

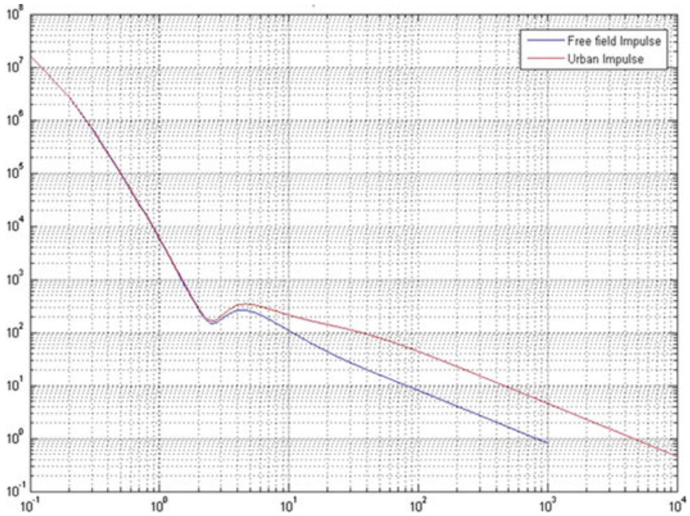

Fig. 4 Comparison of impulse versus standoff [6, 7]

building's failure sequence significantly affect the damage level. Even though there are uncertainties in predicting explosive damage level, it is possible to indicate the overall level of wear and injuries based on the TNT yield, standoff distance, and assumptions about the structure's construction [7].

Damage to the structure can be divided into two types based on the air blast shock wave, i.e., direct air blast effects and progressive collapse. With the association of peak values and impulses of both hydrostatic and dynamic pressure, a specific level of damage or injury can be defined. The degree of harm or injury will be related to the pressures' peak values, and the peak value duration or impulses defined as the time integrals of the pressures during the peak value positive phases. A longer positive phase duration for a massive explosion will have higher peak pressure causing specific damage or injury to the buildings and people [8].

4 Blast Mitigation Tool

In the GUI of the blast mitigation tool, the first and foremost step is loading a geocoded Google map/ user-defined shapefile. For uploading the map, a shapefile has to create a shapefile database, and a path is defined for loading within the defined boundaries of the axes. To enable loading a shapefile, the type or style of objects used are static text and push button. The static text area and push button components are added to the UI, and the components are aligned. After aligning the components, the push button is labeled in the property inspector by modifying the static text in the property inspector. After saving the layout to load shapefile code, the push button's behavior save the UI layout [9]. The input to latitude and longitude is through; the components used are static text and the edit text from the menu control panel. The components are placed in the location panel. The static text and edit text in the property inspectors are labeled and modified before saving the UI layout. The behavior of the edit text is coded by using the callback function of the latitude and longitude.

The map (shapefile) gets the (X Y) coordinates from the cursor and outputs the X-coordinate as latitude and Y-coordinate as longitude. The latitude and longitude are the source centers, i.e., the charge of explosives in kg TNT (Trinitrotoluene). The charge of explosives in kg TNT is given as an input to calculate the peak overpressure, and the time duration of the blast wave and contours are developed (Fig. 5).

The peak overpressure (vs.) distance graph as an input gives the required pressure in kPa units (kilopascal) such as 6.89 kPa (1 psi), 13.79 kPa (2 psi), 20.68 kPa (3 psi), and so on. The data is sorted to get the radius. From the radius, contour with latitude and longitude as the center is developed. The blast peak overpressure contours are converted to a shapefile and placed as a layer over the shapefile of the map. The pressures within the contours correspond to various levels of expected damage to buildings and occupants. Appropriate mitigation measures can be taken according to the damage level predicted within the contour.

Fig. 5 MATLAB GUI (Decision Support Tool)

5 Results and Discussion

- This tool helps to mitigate the blast effect over people and buildings by finding the range of the blast effect contours from the center of the charge and enables urban planners and security agencies to plan for minimum effect due to the blast.
- Contours of 6.89, 13.79, 20.68, 34.47, 68.95, and 137.9 kPa peak overpressure corresponding to various critical levels of blast damage within the radius of these peak overpressures are plotted in a user-defined GUI environment.
  - Within the 6.89 kPa peak overpressure contour, there will not much effect on structures and humans. The structure's effect is just window glass shatters, and light injuries from fragments will occur to people.
  - If the structure is within the 13.79 kPa peak overpressure, the blast causes the effect of moderate damage to houses like windows and doors blown out and severe damage to roofs. For people in this region will have injuries by flying glass and debris.
  - The 20.68 kPa peak overpressure causes the collapse of residential structures. Most people will have serious injuries, and fatalities may occur.
  - For 34.47 kPa peak overpressure, most of the buildings or structures will collapse, and the effect on the people will have universal injuries, and the fatalities are widespread.
  - For the 68.95 kPa peak overpressure, most of the reinforced concrete buildings are severely damaged or demolished, and most of the people are killed because of enormous heat and fire.
  - For the 137.90 kPa peak overpressure, almost all structures in the contour, such as heavily built concrete buildings, are severely damaged or demolished, and the fatalities approach 100%.

6 Scope and Limitations of Work

The presented work focuses on the estimation of blast damage in an urban environment. In the study, some simplifying assumptions are considered to reduce the complexity of implementing the code. The following are the limitations of the study:

- Only explosions caused by high explosives (chemical reactions) are considered within the study. High explosives are solid in form and are commonly termed condensed explosives. TNT (trinitrotoluene) is the most widely known example.
- The shock wave and thus peak overpressures are considered to be modified by interaction with buildings in this article. Within a specified contour region, the peak overpressure and corresponding building damage levels and casualties are constant.
- In this tool, the effect of the negative phase of a blast wave is neglected. The impact of this on actual response and damage is negligible.

7 Conclusion

A self-contained and simple MATLAB® -GUI-based GIS tool has been developed to predict blast damage to buildings and human beings. The conclusions from the study are as follows:

- This tool fills the gap of a self-contained blast mitigation tool that is not publicly available.
- It will enable planners, administrators, and security agencies to predict the amount of damage occurring to the buildings and people based on distance from the center of charge and plan mitigation measures.
- It will help locate the casualties over a wide range in the blast region, and this data will help emergency agencies and first responders prioritize their routes, which can have a tremendous effect on response times and save many lives.

8 Future Study

Within the limited scope of the present work, this work's broad conclusion has been reported. However, further development of the software tool can be undertaken.

- This study can be further to be extended to ground shock also.
- Blast shadow regions and complex reflections and refractions in dense urban areas need to be included to enable more accurate blast pressures.
- The inclusion of the P-I curve-based structural response to blast loading will enable the determination of building-specific damage.

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Pavement Design Considering Changing Climate Temperature

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Abstract Global air temperature is progressively increasing. Presently, conventional flexible pavement is generally designed for a design period of 20 years, and perpetual pavement is designed for a design period of 30–50 years. Therefore, pavement temperature should be designed considering this increasing pavement temperature. Presently, average annual pavement temperature is considered as 35 °C. Based on various research reports, it is presumed that air temperature will rise by 1.5 °C (approximately) in the next 20 years. Thus, the average annual pavement temperature in the coming years should be minimum 37 °C and may go up to 40 °C for conventional pavement and perpetual pavement, respectively. Softening point of bitumen will be increased, and the conventional viscosity grades of bitumen like VG 30 and VG 40 will not be suitable for usage in the bituminous layers of the pavement. Performance grade (PG) or polymer modified bitumen (PMB) with higher softening point may be used to cater for the thermal changes. Air temperature and pavement temperature models have been considered for pavement design. E values of mix at different average annual pavement temperatures (AAPT) are considered, and a correlation has been developed between pavement temperature and E value of mix for VG 40 bitumen and presented graphically. A linear correlation equation has been derived as $E = 10{,}000 - 200 \times \text{AAPT}$. The E values at different temperature will be taken from this equation, and same will be used in pavement design. Two case studies are adopted, i.e., conventional pavement design and perpetual pavement design and presented in this paper. Pavement thicknesses are compared; cost variation and life cycle cost analyses are conducted and presented in this paper.

Keywords Pavement design · Temperature · Resilient modulus

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1 Introduction

Bituminous pavements are environmental sensitive infrastructure. When there is adverse change in environment conditions, pavement deterioration may occur faster; thus, incurring additional costs to the road authorities. If no action is undertaken, the burden will fall on the users in light of loss in safety, time, and fuel consumption. On a national level, this means the total amounting cost incurred because of change in the climate perhaps become significant, and extra financial resources will be required for adaptation of climate and also to mitigate future requirements.

There has been incessant increment of 0.85 °C in surface temperature between 1880 and 2012 round the globe, and the variation in the rate has become swifter in the present decades. Meanwhile, rising in the sea level and drastic changes in weather events, such as hurricanes, floods, and heat waves, have become more common in several areas. In near future, there likely be the change in climatic conditions [1]. So, it is vital requirement to take in account the climatic resilience in pavement design and management; moreover, it is necessary to find (1) How do the interaction between climate and pavements takes place (2) Ongoing researches for evaluating effects of climate behavior on bituminous pavements? (3) Impact of climatic behavior change on bituminous pavement systems (including repair/rehabilitation cycle, performance and financials) in a pavement life cycle perspective? (4) Present gaps in research areas for climate adaptation and mitigation for bituminous pavements.

Generally, environmental conditions can directly be affected by change in climatic conditions and result in variation in pavement performance. The climate stressors could disturb the balance of moisture and energy of pavement and as a result the pavement performance would also be affected directly. From the literature, the mostly used climate stressors are precipitation, groundwater, temperature, wind speed & cloud cover [2]. Typically, pavement performance is most influenced by temperature and moisture, and the long-term impacts from the climate stressors can be significant [3, 4].

2 Future Increase of Pavement Temperature

Presently, conventional flexible pavement is generally designed for the next 20 years, and perpetual pavement is designed for the design period of 30–50 years. Therefore, pavement temperature should be designed considering this increasing pavement temperature. Presently, average annual pavement temperature is considered 35 °C. Based on various research reports, it is presumed that air temperature will rise by 1.5 °C (approximately) in the next 20 years. Thus, the average annual pavement temperature in the coming years should be minimum 37 °C and may go up to 40 °C for conventional pavement and perpetual pavement, respectively. Softening point of bitumen will be increased, and the conventional viscosity grades of bitumen like VG 30 and VG 40 will not be suitable for usage in the bituminous layers of the pavement.

Performance grade (PG) or polymer modified bitumen (PMB) with higher softening point may be used to cater for the thermal changes. Air temperature and pavement temperature models have been considered for pavement design. E values of mix at different average annual pavement temperatures (AAPT) are considered.

2.1 IRC: 37-2018 Provision

The prevalent codal provision for flexible pavement design in India is the IRC: 37-2018 [5], and according to it, VG 40 bitumen is adopted for pavement design. E values of mix using VG 40 bitumen at different temperatures are presented in Table 9.2 of IRC: 37-2018, and relevant values are presented in Table 1.

These results are plotted graphically and presented in Fig. 1. A good co-relation is found, and regression equation is developed and presented in Fig. 1 i.e.,

$$E = -200 \times \text{AAPT} +, 10000 \quad (1)$$

This equation will be useful to determine E values of mix at different pavement temperatures.

Presently, we determine pavement thickness considering AAPT as 35 °C for the next 20 to 30/50 years. It is apparent that this temperature will be increased and exceed 35 °C. It is also apparent that with the consideration of AAPT as 35 °C, we are using a conservative value of *E* in pavement design. It is presumed that

Table 1 Relation among pavement temperature and *E* value of mix

Pavement temperature (°C)	20	25	30	35	40
E value of BC/DBM (MPa)	6000	5000	4000	3000	2000

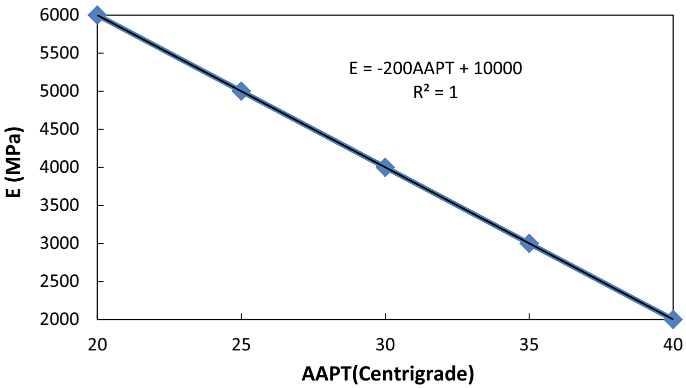

Fig. 1 Correlation between average annual pavement temperature and *E* value of mix

design pavement temperature will be 37 °C, 39 °C, and 40 °C in 2040, 2060, and 2070. Hence, values of E in mix should be considered as 2600 MPa, 2200 MPa, and 2000 MPa, respectively.

Rainfall, solar radiation, latitude, wind speed, and air temperatures are some of the deciding parameters for pavement temperature [6]. Furthermore, among said factors, latitude and air temperature are considered as the important one. In order to frame, regression co-relation, taking into account effect of latitude and air temperature for pavement temperature, linear regression equation with two variables is assumed [7].

The coefficients of the equation are determined by the in-built linear regression function in MATLAB and given as follows [7]:

$$P_t = 0.7147 + 1.3023A_t + 0.1103L \tag{2}$$

where P_t = pavement temperature (°C), A_t = air temperature (°C), and L = Latitude of the selected location.

This equation may be revised as:

$$P_t = 0.7147 + 1.3023A_t + 0.1103L + x \tag{3}$$

where x varies from 1 to 5 depending on future design years which may be 10, 20, 30, 40, and 50 years.

2.2 *Case Studies*

Two case studies are considered. One conventional pavement for the design period of 20 years and perpetual pavement for design period of 50 years are considered for analysis.

2.3 *Conventional Pavement*

Assume design life of 100 MSA and design CBR 10%. Average annual pavement temperature (AAPT) is assumed as 35 °C, 37 °C, 39 °C, and 40 °C, and E values of mix are 3000 MPa, 2600 MPa, 2200 MPa, and 2000 MPa, respectively. IIT Pave software is used to determine pavement thickness and presented in Table 2.

Typical rates are taken for the determination of initial cost of pavement and presented in Table 3.

A typical cross section has been considered for the length of 10 km of road. Unit rates of different construction items are taken based on basic rates of 2018, and initial costs for different pavement temperatures are presented in Table 4 for the year 2020.

Table 2 Pavement compositions

AAPT (°C)	E value of mix (MPa)	Pavement compositions (mm)			
		BC	DBM	WMM	GSB
35	3000	50	110	250	200
37	2600	50	120	250	200
39	2200	50	130	250	200
40	2000	50	135	250	200

Table 3 Typical rates of construction items

Description	Unit	Rates (INR)
BC	Cum	13,000
DBM	Cum	12,000
Tack coat	Cum	15
Prime coat	Cum	30
WMM	Cum	4000
GSB	Cum	3300

Table 4 Initial construction costs

AAPT (°C)	*E* value of mix (MPa)	Total pavement construction cost (Rs Million)[a]
35	3000	81.8
37	2600	84.1
39	2200	86.4
40	2000	87.6

[a]Cost excludes cost of structures, road furniture cost, and miscellaneous item

3 Perpetual Pavement

A case study is considered for perpetual pavement for design CBR of 10%. Average annual pavement temperature (AAPT) is assumed 35 °C, 37 °C, 39 °C, and 40 °C, and E values of mix will be 3000 MPa, 2600 MPa, 2200 MPa, and 2000 MPa, respectively. IIT Pave software is used to determine pavement thickness and presented in Table 5. Pavement compositions have been finalized based on fatigue strain and subgrade strain limits of 80 micron and 200 microns, respectively.

A typical cross section has been considered for the length of 10 km road. Unit rates of different construction items are taken, and initial costs for different pavement temperatures are presented in Table 3. Initial pavement cost has been determined and use for life cycle cost analysis.

Table 5 Pavement compositions

AAPT (°C)	*E* value of mix (MPa)	Pavement compositions(mm)			
		BC	DBM	WMM	GSB
35	3000	50	260	150	200
37	2600	50	280	150	200
39	2200	50	305	150	200
40	2000	50	320	150	200

4 Analysis for Life Cycle Cost (LCCA)

In order to check the feasibility of the design alternatives, LCCA is performed, in particular, to find the most cost-effective alternative to build and maintain. The major costs that are taken in account for LCCA are initial construction cost, rehabilitation cost, maintenance cost, salvage value, user delay (during upcoming maintenance or resurfacing), and vehicle operational cost. The starting four are agency costs that have the most influence on approach selection. While, when considered, the last two user costs may have major effect on selection of approach that is most cost-effective overall [8]. LCCA program uses actual cost to determine the most economic design.

Design life of long-life pavement is considered as 50 years and 20 years for conventional pavement. Routine maintenance, periodic surfacing of pavement is considered at every seventh year for the simplification of analysis. Climatic variation in India varies widely, and overloading vehicles are plying on roads which are not fully controlled. No periodic maintenance data is available in India. Hence, there is a chance of damage of top 50 mm layer due to rut and top-down cracking, and a periodic maintenance is required at every seventh year. Damaging effect during application of load through these seven years is negligible. Based on this assumption, a case study has been considered for new four lanes divided carriageway with pavement compositions as mentioned in Tables 2 and 5 for conventional pavement and perpetual pavement.

Life cycle cost analysis has been carried out for conventional pavement for design periods of 20 years and 50 years for perpetual pavement. Initial cost and life cycle cost are presented in Figs. 2 and 3 for conventional pavement and perpetual pavement.

Initial pavement cost and life cycle cost are determined taking E value of mix from 3000 to 2000 MPa and presented graphically as shown in Fig. 3.

5 Discussion

Due to rapid climate change, pavement temperature is increasing, and presently pavement design temperature is considered 35 °C in major parts of India, but it should be increased considering global warming. Variation of average annual pavement temperature (AAPT) may be increased in the range of 37–40 °C next 50 years. Therefore,

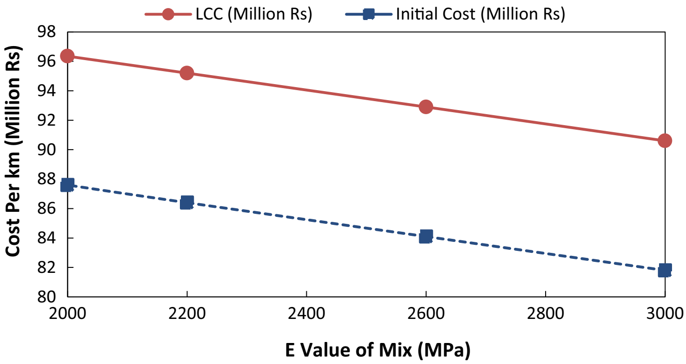

Fig. 2 Initial pavement construction cost and life cycle cost for design traffic 100 MSA

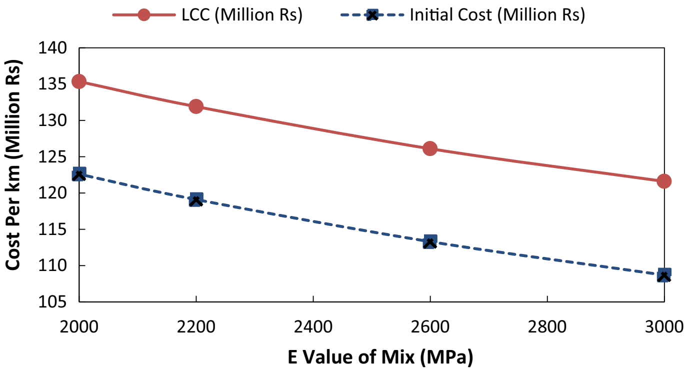

Fig. 3 Initial pavement construction cost and life cycle cost for perpetual pavement. *Note* User delay and vehicle operating cost are excluded in the analysis

this should be incorporated in the pavement design. Therefore, pavement design is adopted varying AAPT from 35 to 40 °C, and two case studies are considered. One of the important inputs for pavement design is *E* value of mix. It is found from Fig. 1 that *E* value of mix decreases linearly with negative slope with increasing temperature, and this demands more asphalt thickness and same is given in Tables 2 and 5 for conventional pavement and perpetual pavement. Initial pavement cost has been determined, and it is found that initial pavement cost increases with increasing pavement temperature for conventional and perpetual pavement. Life cycle cost (LCC) and initial construction cost of pavement are calculated and presented in Figs. 2 and 3 for conventional pavement and perpetual pavement. From these two figures, it is observed that LCC increases with decreasing E Value of mix, i.e., increasing pavement temperature. Therefore, climate change increases initial pavement construction cost and LCC of pavement. Climate aspect may be considered for pavement design.

6 Conclusions

Based on this present study, it is found that climate change aspect should be included in the pavement design. IRC: 37–2018 may be revised/ relooked considering this aspect. Special circular may be issued from Ministry of Transport, Government of India. Based on present study, following conclusions may be drawn:

- Presently pavement design temperature is considered as 35 °C. This may be increased in the range of 35–40 °C in major parts of India.
- Increasing pavement temperature in pavement design increases pavement thickness;
- Initial pavement cost will be increased due to global warming.
- Life cycle cost (LCC) will also be increased.
- Initial pavement cost and LCC vary linearly with negative slope with increasing E value of mix.
- Pavement temperature as mentioned in Eq. 2 may be used for the determination of design pavement temperature considering average value of 12 months.

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Application of GIS and AHP-Based Integrated Methodology for Mapping and Characterizing Socioeconomic Vulnerability to Natural Hazards: A Case Study of Southwestern Coastal Bangladesh

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Abstract Southwestern Coastal Bangladesh is well-known for its vulnerability to natural hazards and climate-induced disasters. However, a little initiative is taken by the national and international organizations to analyze the vulnerability condition of this coastal region with consistently undervaluing the importance of socioeconomic factors. Consequently, no detailed vulnerability map is provided, and the ability to plan for effective disaster management is hindered. Additionally, over the past decade, socioeconomic vulnerability assessment has been recognized as an effective and leading tool to analyze the nature and extent of human vulnerability to climate-induced stress and natural hazards. Thus, this study analyzes and characterizes the vulnerability of the southwestern coastal communities considering the major socioeconomic factors that influence spatial vulnerability's differentiated nature. We have selected 20 indicators to construct the socioeconomic vulnerability index under three major components: physical and infrastructural, socio-demographic, and economic components. We have considered census data for all the twenty indicators published by the Bangladesh Bureau of Statistics. Spatial data analysis has been completed by following three major steps: Firstly, the major component-specific index value is generated using "indexing method" and "analytical hierarchy process"; secondly, all the major components value is converted into maps at the local level using geospatial techniques; and thirdly, the overall vulnerability map is produced through integrating all the major components. The results demonstrate the extent of socioeconomic vulnerability as very high (17.8%), high (46.6%), moderate (21.7%), low (11.5%), and very low (2.4%). In general, eastern, central, and southern regions exhibited a higher vulnerability than the northwest part of the study area. This study is crucial for policymakers to make decisions regarding development strategies and to plan for disaster risk reduction by exploring the level and extent of vulnerability at the local level.

Keywords Socioeconomic vulnerability · Natural hazard · Indexing · Geographic information system (GIS) · Analytical hierarchy process (AHP) · Bangladesh

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1 Introduction

Bangladesh is marked as one of the most natural disaster-prone countries in the world [1, 2], which is ascribed to the geographical setting of the country that makes it most vulnerable to natural hazards (i.e., cyclone, tidal surge, drought, flood, earthquake, salinity intrusion, tornado, river erosion). The flat topography, heavy monsoon rainfall, discharge of sediments, drainage congestion, active fault line, low river gradients, and shallow funnel-shaped Bay of Bengal are the major factors behind the frequent landfall of different natural hazards in Bangladesh [1]. These natural occurrences frequently disrupt local inhabitants' existence by injuring/damaging the population, economy, property, infrastructure, lifelines, and agricultural land [3, 4]. Thus, it is important to develop and deploy an advanced integrated methodology to assess and map the associated socioeconomic vulnerability to natural hazards to inform better disaster management framework, policy planning, and decision-making. Therefore, this study concentrates on applying GIS and AHP-based integrated methodology for analyzing spatial extents and levels of associated socioeconomic vulnerability to natural hazards in the southwestern region of Bangladesh.

Vulnerability is conceptualized in various ways by different research communities as most of the vulnerability research is highly interdisciplinary in nature, which provides numerous approaches to theorize and analyze different components of vulnerability [5, 6]. In 1992, Dow [7] defined vulnerability as the degree to which a system, sub-system, individual, group, or community is likely to be affected by exposure to natural hazards based on the condition of differential physical and social attributes. Similarly, Adger [8] defined vulnerability as the negative consequence of external stressors or hazards on the life and livelihood of individuals, groups, or communities. Again, social vulnerability refers to an individual or group's inability to respond to and recover from the impacts of any external shock placed on their livelihood and well-being [5]. The prime difference between the traditional view of vulnerability and social vulnerability is the separation of biophysical parameters from the human dimension of vulnerability. The assessment of social vulnerability covers various attributes, such as density, education, well-being, race, age, social class, employment, ethnicity, elderly population, quality of the built environment, which provide much-needed insights into the sensitivity and susceptibility of a system for hazard time planning and response.

Over the past decade, mapping and characterizing vulnerability to natural hazards have emerged as an important technique to support risk management, preparedness plan, emergency response plan, and evaluation plan across the Global South [9, 10]. However, most of the studies on coastal communities' vulnerability are concentrated on physical factors, ignoring the local level social, economic, and cultural attributes, which provide a more realistic assessment of potential hazard impact. Thus, a vulnerability assessment exclusively concentrated on socioeconomic components will be imperative for understanding disaster impact and formulating appropriate management strategies. On this basis, this study intends to address the last critique of vulnerability assessment and aims for a cerebral discussion of socioeconomic vulnerability using a pragmatic approach.

Many tools and techniques are available in global literature to assess vulnerability to natural hazards at different spatial scales. Sahana et al. [11] followed an indexed-based geospatial approach to assess the socioeconomic vulnerability of 38 villages to climate-induced disasters in the Sundarbans Biosphere Reserve, India. Alam and Haque [12] integrated technique for order preference by similarity to ideal solution method (TOPSIS) and analytical hierarchy process (AHP) with spatial analysis tools for the assessment of vulnerability to the earthquake in the residential area of Mymensingh City, Bangladesh. Choudhary et al. [13] used a spatial modeling approach to understand natural and environmental vulnerability based on remote sensing and geophysical data in Astrakhan, Russia. In this study, we applied a multi-criteria analysis technique to assess socioeconomic vulnerability to natural hazards that integrate the indexing method and analytical hierarchy process (AHP) using geospatial techniques to quantify, characterize, and map the degree of vulnerability for the southwestern coastal region of Bangladesh.

The relationship between hazard and vulnerability has been considered in many studies, yet mapping and characterization of vulnerability considering the coastal communities' socioeconomic profile have not been done in Bangladesh. Moreover, there are no individual vulnerability scales to identify the probable impact of a particular hazard. To make the information readily available for the stakeholders, it is necessary to prepare a vulnerability map to identify the vulnerable zones easily. This study will help planners, policymakers, and disaster managers to make decisions regarding risk-sensitive land use planning, layout planning, land use management, building improvements, formulation of development strategies, adaptation planning, sustainable livelihood planning, etc., for different locations considering the different aspects of respective socioeconomic vulnerability to natural hazards.

2 Materials and Methods

This study aims to analyze, characterize, and map the socioeconomic vulnerability of coastal communities to natural hazards via integration of the analytical hierarchy process (AHP) and index method using geospatial techniques. To achieve this goal, the following steps are considered.

2.1 Study Area

Bagerhat, Khulna, and Satkhira districts in Bangladesh are selected as the case study site (cf. Figure 1) for this study because of their dynamic nature of physical and

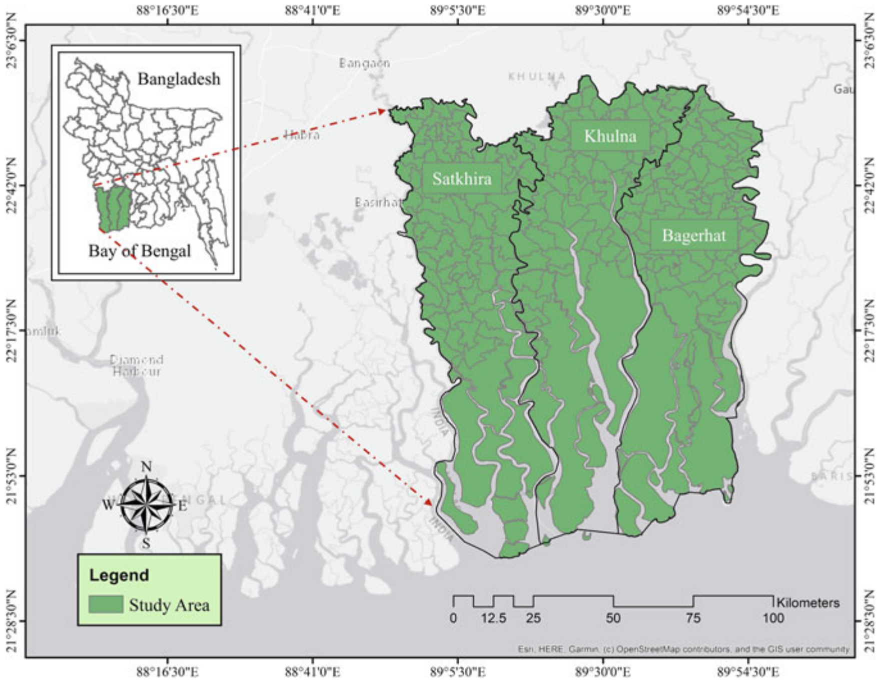

Fig. 1 Map of the study area. *Source* Generated by authors using the data provided by the Local Government Engineering Department (LGED)

geological factors. These three districts approximately occupy 12,211 km^2. of land area with an average population density of 474 per km^2 [14]. The area lies between 21°40′ and 22°58′ north latitudes and between 88°53′ and 89°59′ east longitudes. The Bay of Bengal is situated in the southern part of the study area, including the world's largest mangrove forest with a dynamic ecosystem, important biodiversity, and aquatic resource. The main source of livelihoods of the rural inhabitants living in these areas is farming, fisheries activity, animal husbandry, and the Sundarbans' resources. These three districts are susceptible to many natural hazards, ranging from frequent, regularly occurring hazards (e.g., tidal surge, flood) to less frequent but higher magnitude hazards such as cyclone and tornado. Floods, for example, occur regularly during heavy precipitation events and the annual monsoon season, whereas large-scale cyclones or tornados occur periodically.

2.2 Data Collection and Analysis

This study is performed based on the secondary data source. The geo-referenced vector map of the smallest administrative unit (also known as Union) is collected

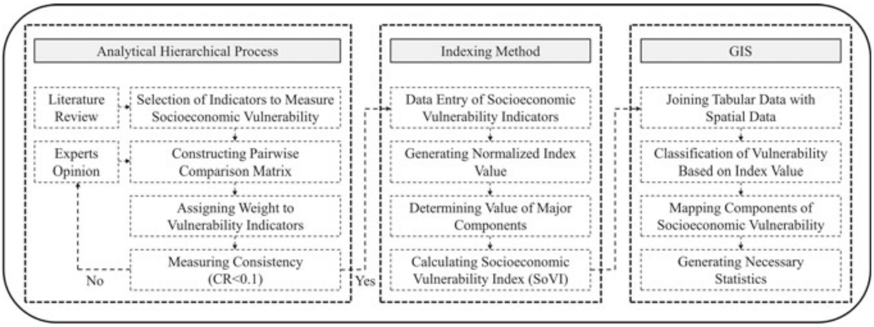

Fig. 2 Methodological framework of the study

from the Local Government Engineering Department (LGED) of Bangladesh [15], and the socioeconomic data for each of the administrative units (Unions) is extracted from the Population and Housing Census of Bangladesh, 2011 [14].

The methodological framework that is followed for the fulfillment of this study is presented in Fig. 2. Based on the literature review, we included three major components (that comprise a total of 20 indicators) to measure socioeconomic vulnerability index (SeVI) (cf. Appendix 1). Appendix 1 includes an explanation of how each indicator is quantified and its functional relationship with vulnerability. Additionally, for each of the major components and indicators, weight is assigned based on the analytical hierarchy process (cf. Appendix 2).

2.3 Analytical Hierarchy Process (AHP)

Analytical hierarchy process (AHP) is a powerful mathematical method developed by Saaty [16] for estimating the weight of variables based on experts‘ opinions. This study used five experts' responses with thorough experience of vulnerability analysis and mapping to generate the weights. The AHP-derived weights are further used for the calculation of socioeconomic vulnerability indices based on multiple criteria. The AHP method follows three steps to generate weights for a set of variables or criteria. In Step 1, a comparison matrix is generated on a scale of 1–9 based on the experts' response in which 1 refers to equally important factors and 9 indicates the extreme importance of a factor over another. The scale of importance, developed by Saaty [16], required to fill up the AHP questionnaire is shown in Table 1.

In Step 2, a normalized matrix is generated by totaling the value of each column of the comparison matrix and then dividing each entry of a column by the sum of that column. After normalization of each column following the same procedure, the sum of each column of the matrix must be 1.

In Step 3, the consistency ratio (CR) is measured using Eqs. 1 and 2 to evaluate the consistency of experts‘ judgments. A CR value above 0.10 indicates that the

Table 1 Magnitude of importance for pairwise comparison

Intensity of importance	Definition
1	Equal importance
2	Weak or sight
3	Moderate importance
4	Moderate plus
5	Strong importance
6	Strong plus
7	Very strong or demonstrated importance
8	Very, very strong
9	Extreme importance

Table 2 RI values for the corresponding number of variables [16]

N	1	2	3	4	5	6	7	8	9	10	11	12
RI	0	0	0.58	0.9	1.12	1.24	1.32	1.41	1.45	1.49	1.52	1.54

comparison matrix has inconsistency that is unacceptable. Thus, it needs to be iterated or revised until it shows acceptable consistency (CR < 0.1).

$$\text{Consistency Index, CI} = \frac{\lambda_{\max} - n}{n - 1} \tag{1}$$

$$\text{Consistency Ratio, CR} = \frac{\text{CI}}{\text{RI}} \tag{2}$$

Here, $\lambda_{\max}$ = maximum eigenvalue of the matrix, n = dimension of the matrix, and RI = random index. The variation of the RI value depends on the number of variables, which is shown in Table 2.

The weights assigned for each of the major components and sub-components of socioeconomic vulnerability following the AHP method are listed in Appendix 2. The consistency ratio of all the AHP model satisfied the criteria of CR value less than 0.1, which indicates the consistency of all the matrix.

2.4 Construction of Composite Socioeconomic Vulnerability Index (SeVI)

The indexing approach is based on a total of 20 indicators or sub-components under three dimensions or major components for developing "socioeconomic vulnerability index (SeVI)" (cf. Appendix 1). The methodology used for indexing in this research follows the calculation procedure of the "livelihood vulnerability index (LVI)" [17], "climate vulnerability index (CVI)" [18], and "household livelihood vulnerability index (HLVI)" [19, 20]. The indexing method comprises three steps to generate SeVI for each Union (local-level administrative unit). In Step 1, all the sub-components are normalized to make them comparable (as sub-components are in different unit or scale) using Eqs. 3 and 4. Equation 3 is used to normalize the sub-components with a positive functional relationship, and Eq. 4 is used to normalize the sub-components with a negative functional relationship.

$$\text{Index}_{N_s} = \frac{X_s - X_{\min}}{X_{\max} - X_{\min}} \tag{3}$$

$$\text{Index}_{N_S} = \frac{X_{\max} - X_s}{X_{\max} - X_{\min}} \tag{4}$$

Here, Index_{N_S} is the normalized index value of a sub-component for Union *S*, and X_s is the actual value of the sub-component for Union *S*. $X_{\max}$ and $X_{\min}$ refer to the maximum and minimum values of the sub-component among all the Union. After normalization, in Step 2, the value of major components for each of the Union is calculated using Eq. 5.

$$M_s = \sum_{i=1}^{n} \text{Index}_{N_S^i} \times W_{SC^i} \tag{5}$$

Here, M_s refers to the value of one of the major components (socio-demographic component (SDC), economic component (EC), physical and infrastructural component (PIC)) for Union *S*, $\text{Index}_{N_s^i}$ is the normalized index value of the *i*-th sub-component for Union *S*, W_{SC^i} is the weight of the *i*-th sub-component that is derived from the AHP, and *n* is the total number of sub-components under the corresponding major component. Once the value of major components for all the Unions are calculated following the same procedure, Eq. 6 is used to obtain the socioeconomic vulnerability index (SeVI) value for each of the Unions.

$$\text{SeVI}_s = (\text{SDC}_s \times W_{\text{SDC}}) + (\text{EC}_s \times W_{\text{EC}}) + (\text{PIC}_s \times W_{\text{PIC}}) \tag{6}$$

Here, SeVI_s = value of socioeconomic vulnerability index for Union *S*, SDC_s = value of socio-demographic component for Union *S*, EC_s = value of economic component for Union *S*, and PIC_s = value of physical and infrastructural component for Union *S*. W_{SDC}, W_{EC}, and W_{PIC} are the AHP-derived weights of socio-demographic component (SDC), economic component (EC), and physical and infrastructural component, respectively.

3 Results and Discussions

To illustrate the findings, this section is summarized into two main parts as (i) spatial pattern and spatial variation of vulnerability under different major components are mapped and analyzed; and (ii) socioeconomic vulnerability is presented through investigating and mapping the index score of the Unions.

3.1 Individual Assessment of Vulnerability Components

This study has developed the socio-demographic, economic, and physical and infrastructural indices by integrating the corresponding indicators/sub-components' value and weight. Afterward, we have produced a comprehensive vulnerability map for each of the components and quantified the degree of vulnerability to natural hazards by categorizing the index score into five levels (i.e., very low, low, moderate, high, and very high). The index score ranges between 0 and 1, where a higher value represents high vulnerability and vice versa. Following Mudasser et al. [20], the categorization is done by dividing the range between the highest and lowest index score of a component into five equal distance intervals.

The study area comprises Satkhira, Khulna, and Bagerhat districts with 3858.36 km^2, 4394.45 km^2, and 3959.11 km^2. However, due to the Sundarbans and enormous rivers across the district, the actual human habitable area of Satkhira, Khulna, and Bagerhat is, respectively, 2243.24 km^2, 2054.99 km^2, and 2011.29 km^2. Moreover, the Satkhira, Khulna, and Bagerhat districts include 79, 97, and 77 Unions (smallest administrative unit in Bangladesh), respectively, which together (253 Unions) represents the entire Southwestern Coastal Bangladesh. In this study, analysis and statistics are performed only for the habitable areas and registered Unions. The component-specific map of vulnerability will help decision-makers, disaster managers, and responsible stakeholders better understand the complex vulnerability scenario at the Union level. It will help to make effective and efficient spatially targeted policies to increase the resilience of coastal communities.

Socio-demographic Component The vulnerability map of the socio-demographic component (cf. Figure 3) portrays the greatest vulnerable areas as the northeast region along Khulna and Bagerhat districts and the southern region along the coast of Satkhira. The central part of the study area is classified as a low or moderate vulnerability zone. The variation in the degree of vulnerability based on the socio-demographic component for a total of 253 Unions of Satkhira, Khulna, and Bagerhat districts is presented in Table 3. Most of the Unions are registered in moderate vulnerability class for all the regions and only a few in very high vulnerability class. Interestingly, high and low vulnerability persist almost equally across the study area, and very low vulnerability is completely absent in the Satkhira district.

Economic Component The variation in the degree of economic vulnerability (cf. Table 4) across the study area represents that most Unions are in a highly vulnerable

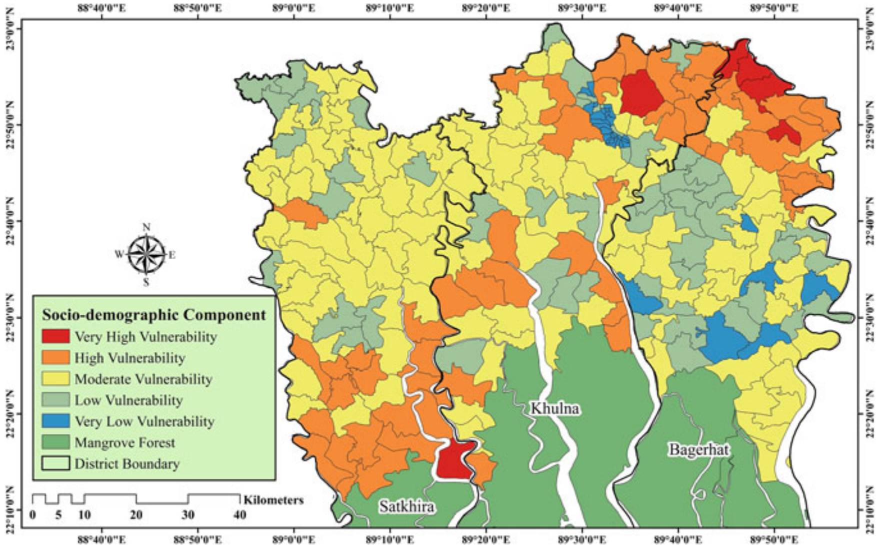

Fig. 3 Degree of vulnerability based on the socio-demographic component at Union level

Table 3 Variation in the degree of vulnerability based on the socio-demographic component

Region		Degree of vulnerability (SDC)				
		Very high	High	Moderate	Low	Very low
Satkhira	Union (count)	1 (1.3%)	17 (21.5%)	47 (59.5%)	14 (17.7%)	0 (0%)
	Area (km^2)	33.73	545.11	1351.96	312.44	0
Khulna	Union (count)	1 (1%)	22 (22.7%)	32 (33%)	16 (16.5%)	26 (26.8%)
	Area (km^2)	49.92	690.45	947.27	331.47	35.88
Bagerhat	Union (count)	4 (5.2%)	12 (15.6%)	32 (41.6%)	23 (29.9%)	6 (7.8%)
	Area (km^2)	89.72	315.80	912.02	538.12	155.63
SW BD (Total)	Union (count)	6 (2.4%)	51 (20.2%)	111 (43.9%)	53 (20.9%)	32 (12.6%)
	Area (km^2)	173.38	1551.35	3211.24	1182.02	191.51

condition. The very high, high, and moderate vulnerability classes account for 91.3% of 253 Unions. This is due to the acute unemployment, economic, and agricultural dependency over the southwestern belt, which is often exacerbated by catastrophic natural hazards. Furthermore, this area is susceptible to climate change and climate-induced disaster, which continuously imprints a negative impact on the life and livelihood of coastal communities. The vulnerability map of the economic component (cf. Figure 4) clearly shows the dominance of very high, high, and moderate vulnerability over the study area.

Physical and Infrastructural Component The vulnerability map of the physical and infrastructural component (cf. Figure 5) portrays a semi-circular concentric zone

Table 4 Variation in the degree of vulnerability based on the economic component

Region		Degree of vulnerability (EC)				
		Very high	High	Moderate	Low	Very low
Satkhira	Union (count)	7 (8.9%)	59 (74.7%)	13 (16.5%)	0 (0%)	0 (0%)
	Area (km^2)	223.06	1712.34	307.85	0	0
Khulna	Union (count)	9 (9.3%)	47 (48.5%)	21 (21.6%)	19 (19.6%)	1 (1%)
	Area (km^2)	333.70	1465.42	208.15	44.78	2.93
Bagerhat	Union (count)	23 (29.9%)	45 (58.4%)	7 (9.1%)	2 (2.6%)	0 (0%)
	Area (km^2)	694.35	1103.57	190.81	22.55	0
SW BD (Total)	Union (count)	39 (15.4%)	151 (59.7%)	41 (16.2%)	21 (8.3%)	1 (0.4%)
	Area (km^2)	1251.10	4281.33	706.81	67.33	2.93

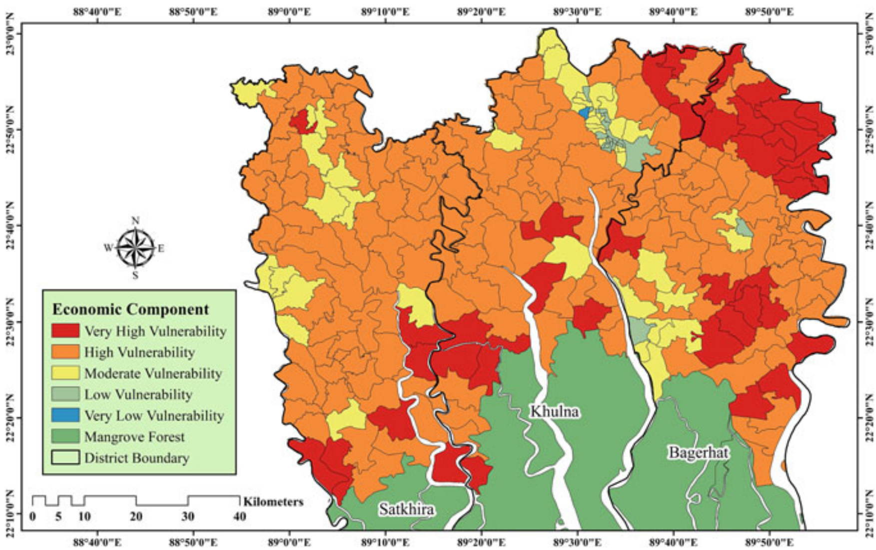

Fig. 4 Degree of vulnerability based on the economic component at Union level

pattern across the study area. The first zone closest to the Sundarbans and the coast is the very high or high vulnerability zone. The second and middle zone is a moderate vulnerability zone. Finally, the third or peripheral zone is classified as a low or very low vulnerability zone. This map represents that the communities living across the coastal belt of Southwestern Bangladesh have a high physical and infrastructural vulnerability, although they are most sensitive to the effect of natural hazards due to their relative distance from the coast. The variation in the degree of physical and infrastructural vulnerability for a total of 253 Unions of Satkhira, Khulna, and Bagerhat districts is presented in Table 5.

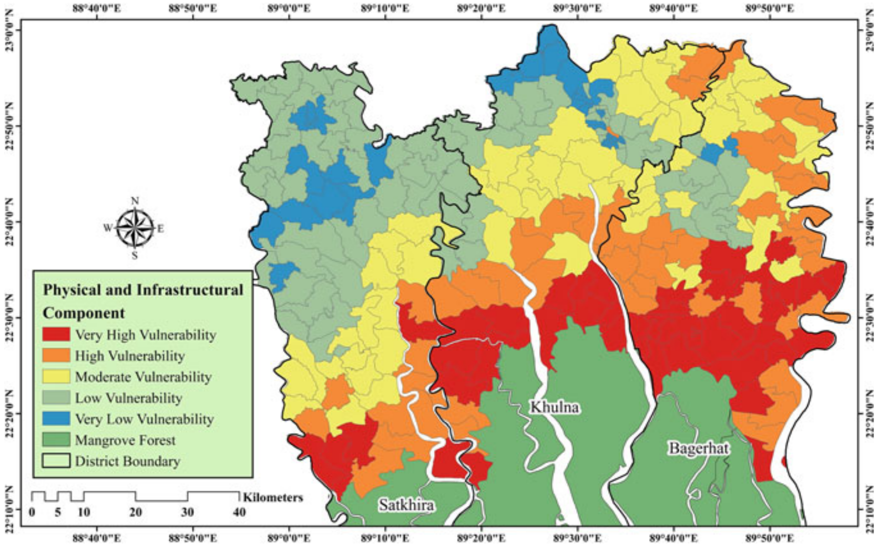

Fig. 5 Degree of vulnerability based on the physical and infrastructural component at Union level

Table 5 Variation in the degree of vulnerability based on the physical and infrastructural component

Region		Degree of vulnerability (PIC)				
		Very high	High	Moderate	Low	Very low
Satkhira	Union (count)	5 (6.3%)	9 (11.4%)	16 (20.3%)	38 (48.1%)	11 (13.9%)
	Area (km^2)	186.51	303.55	501.35	1001.99	249.86
Khulna	Union (count)	13 (13.4%)	13 (13.4%)	19 (19.6%)	27 (27.8%)	25 (25.8%)
	Area (km^2)	412.75	428.97	650.64	414.16	148.47
Bagerhat	Union (count)	23 (29.9%)	26 (33.8%)	19 (24.7%)	8 (10.4%)	1 (1.3%)
	Area (km^2)	640.18	687.55	457.05	207.90	18.60
SW BD (Total)	Union (count)	41 (16.2%)	48 (19%)	54 (21.3%)	73 (28.9%)	37 (14.6%)
	Area (km^2)	1239.43	1420.07	1609.03	1624.05	416.93

3.2 *Composite Socioeconomic Vulnerability*

Social vulnerability is the outcome of social, demographic, economic, and physical factors that together influence the capacity of an individual or community to fight against the adverse impact of natural hazards. Social vulnerability assessment is crucial for understanding the impact of natural hazards at the root level. Thus, this study's central focus was to develop a comprehensive socioeconomic vulnerability map and characterize the degree of vulnerability of the southwestern region of Bangladesh to natural hazards. Therefore, in this section, all the vulnerability components are integrated to produce the composite socioeconomic vulnerability map, which is further categorized into five levels based on the composite index score (i.e., very low, low, moderate, high, and very high).

Analysis of composite socioeconomic vulnerability across the study area represents that most of the Unions are registered in very high (17.8%) and high (46.6%) vulnerability classes (cf. Figure 6). Moreover, the moderate, low, and very low vulnerability classes account for 35.6% of 253 Unions. The composite socioeconomic vulnerability map (cf. Figure 7) clearly shows the dominance of different degrees of vulnerability over the study area. The map portrays that the greatest socioeconomic vulnerability is evident in the northeast region of the study area along Khulna and Bagerhat districts and the southern region along the coast of Satkhira. The high vulnerability class is most commanding and evident discretely across the study area. The central (for Bagerhat), northwest (for Satkhira), and city (for Khulna) regions of the study area are classified as moderate, low, or very low vulnerability zone.

The summary statistics of socioeconomic vulnerability among different regions of the study area is presented in Table 6. It shows that, for all the regions, most of the Unions are registered in the high vulnerability class and only a few in the low vulnerability class. Unsurprisingly, these results show the existing high vulnerability condition of the coastal communities to natural hazards. It also exhibits the limited odds of finding a low vulnerability area in Southwestern Coastal Bangladesh.

This study's findings will help planners, disaster managers, NGOs, communities, and stakeholders promote resilience building and vulnerability reduction activities. It will also contribute to formulate a holistic vulnerability framework, suggesting appropriate adaptive measures and robust coastal management plans for vulnerable areas. Furthermore, it will be a detailed notebook of vulnerability assessment for Southwestern Bangladesh.

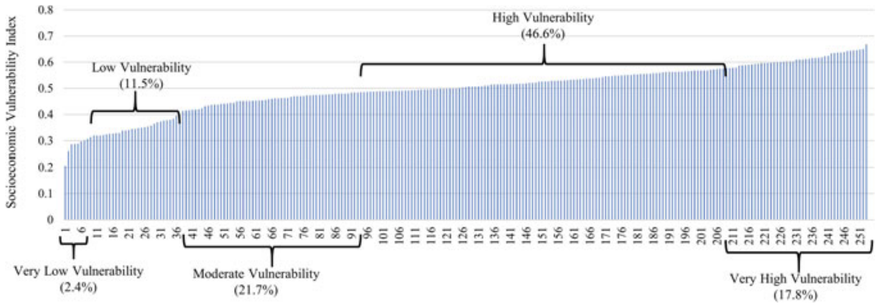

Fig. 6 Unions registered into different vulnerability classes based on composite socioeconomic vulnerability index (SeVI)

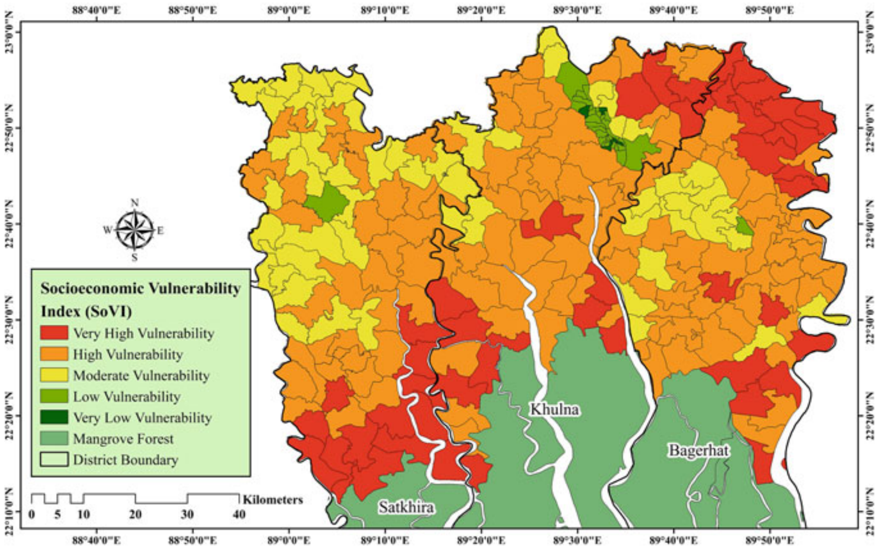

Fig. 7 Composite socioeconomic vulnerability map at Union level

Table 6 Spatial variation of socioeconomic vulnerability to natural hazards

Region		Degree of vulnerability (SeVI)				
		Very high	High	Moderate	Low	Very low
Satkhira	Union (count)	13 (16.5%)	34 (43%)	31 (39.2%)	1 (1.3%)	0 (0%)
	Area (km^2)	454.54	986.65	769.24	32.81	0
Khulna	Union (count)	12 (12.4%)	42 (43.3%)	10 (10.3%)	27 (27.8%)	6 (6.2%)
	Area (km^2)	433.64	1310.31	209.27	94.71	7.05
Bagerhat	Union (count)	20 (26%)	42 (54.5%)	14 (18.2%)	1 (1.3%)	0 (0%)
	Area (km^2)	581.16	1077.06	346.33	6.74	0
SW BD (Total)	Union (count)	45 (17.8%)	118 (46.6%)	55 (21.7%)	29 (11.5%)	6 (2.4%)
	Area (km^2)	1469.34	3374.02	1324.83	134.26	7.05

4 Conclusion

This study has explored the nature and extent of socioeconomic vulnerability in Southwestern Coastal Bangladesh using a pragmatic approach. For the first time, the socio-demographic, economic, physical and infrastructural components are integrated for a large-scale assessment of vulnerability to natural hazards using GIS and AHP. The method used in this study for generating and mapping the composite socioeconomic vulnerability index (SeVI) is very flexible and can be applied in any geographical location easily. In data-scarce regions, this method can be replicated based on small-scale social data. The method is also accommodating to use remote sensing imagery, spatial data, field data, census data, and key information from the local government. The methodological approach and results of this study can be used by the concerned authorities to develop and apply an effective vulnerability mitigation plan.

The component-specific vulnerability map and socioeconomic vulnerability map illustrate the degree and spatial variation of vulnerability to natural hazards for Satkhira, Khulna, and Bagerhat districts, representing Southwestern Coastal Bangladesh. It reveals that the coastal blocks are highly and very highly vulnerable to natural hazards. It also highlighted differential vulnerability among the Unions based on different components and SeVI value, which should be considered while preparing a site-specific action plan, resource allocation plan, land use plan, livelihood sustainability plan, and master plan. Additionally, the findings are consistent with the empirical knowledge of the study area. Furthermore, this study initiates a substantial effort to comprehend the spatially varying exposure and socioeconomic aspects of a vulnerability that fabricate spatial diversity in the risk portfolio.

Appendix 1

See Table 7.

Appendix 2

See Table 8.

Table 7 Indicators to measure socioeconomic vulnerability to natural hazards

Major components	Indicators/sub-components	Explanation	FR[a]
Socio-demographic component (09)	Population density (person/km^2) [21]	Number of inhabitants per square kilometer	+
	Household size (person/HH) [22, 23]	The average number of inhabitants living in one household	+
	Sex ratio (ratio) [22]	Ratio of male and female population (woman = 100)	−
	Young children index (%) [11, 21, 22]	Number of people aged 0–14 per 100 inhabitants	+
	Senior citizen index (%) [11, 21–23]	Number of people over the age of 65 per 100 inhabitants	+

(continued)

Table 7 (continued)

Major components	Indicators/sub-components	Explanation	FR[a]
	Literacy rate (%) [11, 22, 23]	Percentage of population aged 7 and above who can write a letter	−
	School attendance (%) [11, 21, 22]	Percentage of population aged 3–14 and attending school	−
	Minority population (%) [22, 23]	Percentage of ethnic and floating population	+
	Disability (%) [19, 23]	Percentage of population with disability (e.g., physical, mental, autistic)	+
Economic component (06)	Economic dependency (%) [11]	Number of economically inactive per 100 persons of working age	+
	Unemployment status (%) [11, 21–23]	Percentage of population aged 7 and above not attending school and not employed	+
	Working age population (%) [22]	Number of people aged 15–64 per 100 inhabitants	−
	Agricultural employment (%) [11, 23]	Share of agricultural employment in total employment	+
	Service and industry employment (%) [22]	Share of service and industry employment in total employment	−
	Female employment (%) [22]	Percentage of female employed in earning activity	−
Physical and infrastructural component (05)	Kutcha/Jhupri housing structure (%) [19]	Percentage of households having kutcha or Jhupri housing structure	+
	Water source (%) [22, 23]	Percentage of households without tubewell/tap as a water source	+
	Toilet facilities (%) [11, 22, 23]	Percentage of households having the non-sanitary toilet	+
	Electricity connection (%) [23]	Percentage of households without electricity connection	+
	Tenancy status (%) [22, 23]	Percentage of households that live in rented houses	+

[a]FR refers to the functional relationship (positive/negative) of indicators with socioeconomic vulnerability.

Table 8 Calculation of weights for each indicator through the analytical hierarchy process (AHP)

Major components	Local weight	Indicators/sub-components	Local weight	Global weight
Socio-demographic component	0.490	Population density	0.323	0.158
		Household size	0.103	0.051
		Sex ratio	0.018	0.009
		Young children index	0.075	0.037
		Senior citizen index	0.133	0.065
		Literacy rate	0.201	0.099
		School attendance	0.026	0.013
		Minority population	0.078	0.038
		Disability	0.041	0.020
Economic component	0.312	Economic dependency	0.127	0.040
		Unemployment status	0.334	0.104
		Working age population	0.270	0.084
		Agricultural employment	0.136	0.042
		Service and industry employment	0.088	0.028
		Female employment	0.044	0.014
Physical and infrastructural component	0.198	Kutcha/Jhupri housing structure	0.420	0.083
		Water source	0.145	0.029
		Toilet facilities	0.063	0.013
		Electricity connection	0.129	0.026
		Tenancy status	0.242	0.048

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Resilient Sustainable Land Use Planning for Climate Change Adaptation for an Urban Area

Meghna Anilkumar and Shyni Anilkumar

Abstract Sustainability in terms of resilience to climate change is directly related to the land use of the region. Interaction between land, water and human settlement has a significant role in resilience of any urban area. The adaptability of the cities depends on how the region contributes to, resist, reacts and revise itself from impacts of climate change and other natural hazards. Analysing the conditions based on land use for adaptability of Indian cities that experience climate change and flood hazard revealed the inefficiency of the regulatory mechanism and structural measures which was aggravated by anthropogenic causes. Exploring land use practices and coping mechanisms of cities from different parts of the world revealed that there are numerous options that are tried and tested but each approach has to be modified and adapted to the context, in conjunction with various other approaches. This led to structuring of the approaches identified in regional and area-based categories and thereby identifying a pathway for its adoption into mainstream decision making. The study helps policymakers to develop a sustainable resilient urban environment.

Keywords Sustainability · Resilience · Land use planning · Climate change · Watershed · Flood · Adaptability · Natural hazards

1 Introduction

There is ever-increasing danger of climate change globally. Future projections of climate change impact urban regions the most by virtue of high population density and dynamic socio-economic and built-environment. Conversely, urban centers also contribute to global warming and climate change as they are the epic centre of economic prosperity. Climate change may be due to natural internal processes or external forcing, or due to persistent anthropogenic changes in the composition of the atmosphere or in land use [1].

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Agenda 21 advocates for sustainable development through appropriate land use planning and management. Various national policies such as National Land utilization policy and National Action Plan on Climate change recognize the need for sustainable development for resilience [2]. The Sendai Framework for Disaster Risk Reduction 2015–2030 had strengthened the need for disaster preparedness and management [3]. The study is based on established argument that land use change can have an impact on local as well as global climate. Study intents to bridge the gap between planning and disaster management through adaptation and also between climate change studies and land use planning [4, 5].

Flooding is one of the most common and devastating natural hazards, which is more often aggravated by mismanagement of land use. The study focuses on establishing theoretical grounds for incorporating resilience into city planning in the context of flood hazards. The study analyses the relationship between land use planning, resiliency to climate change and sustainability of settlements. Scenarios across the globe are studied to understand the adaptability and thereby develop an approach for resilient planning for a city. Land use planning is understood as a systematic and iterative procedure carried out in order to create an enabling environment for sustainable development of land resources that meets people's needs and demands [6].

The interrelation between climate change, land use and disaster management was studied for understanding it from the perspective of resilient sustainable land use planning. The first objective was to understand the existing scenario and the need for land use adaptation by exploring the current adaptability to climate change and natural hazards. This included studying the existing land use based guidelines and practices in an urban region and also analyzing its adaptability by understanding relationship between the prevailing land use and its influence in context of climate change. The second objective was to understand climate change adaptation models and frameworks for an urban region. This included identification and evaluation of best practices through global literature and thereby identifying potential approaches and strategies applicable in a watershed-urban interaction scenario. The third objective consists of developing an approach for climate change adaptation through resilient land use. This part includes understanding the context of urban development patterns and their vulnerability due to climate change and identifying areas for intervention.

2 The Indian Scenario and Adaptability

Four Indian cities namely Bihar, Uttarakhand, Chennai and Mumbai, with different scenarios and scales of development but with the commonality of occurrence of water-related hazard and their significance in terms of socio-cultural and geographical context were selected to study their adaptability in the Indian context.

Bihar is the most flood-prone state of India, with 22% of the land affected during flooding. It is drained by the river Ganga and its tributaries. The state is located downstream of Himalayas that drains a large quantity of water combined with a very high precipitation rate. River migration and meanders are commonly seen in rivers like Kosi. The relatively flat topography combined with increased flood occurrences increases sedimentation [7, 8]. Uttarakhand has a population of 10 million residents and sees a tourist inflow of 25 million. It is one of the prominent religious and adventure tourism destinations. The state is at the immediate foothills of Himalayas with a major portion of the state being part of Himalayan mountain ranges. There have been many landslides combined with floods in the state [9]. The most devastating example of the disaster the region experienced was the floods of 2013. Extreme rainfall, as well as the very undulating and unstable topography are the direct causes for the region's increased vulnerability. The soil condition of the Himalayan hills and the velocity of river that weathers the rocks cause muck deposits at the settlement areas [10, 11]. Mumbai with a population density of 19,652 persons per square kilometre, has an increased vulnerability due to its sheer exposure of high population and infrastructure to the hazard risks. High rainfall combined with increased surface water runoff leads to waterlogging in areas between the landfilled and the sea reclaimed islands of Mumbai [12, 13]. Chennai has a different scenario compared to the other three states mentions above. It is the largest industrial and commercial centre of south India. The region has a flat topography with no natural gradient [14].

2.1 Anthropogenic Causes

In the case of Bihar dams and embankments have led to water stagnations when the water overflow over the embankments. The natural drainage of the flood plain is obstructed with these structural measures. At locations where the levee has a break, water gushes in with intense force further leading to disastrous events. Addition of transport lines parallel to embankments aided in trapping the water post flood. Residents ultimately live in temporary shelters on the levees surrounded by pools of water on one side and danger from flooding of rivers on the other side [15]. The levees are made by landowners with no regard to the regional setting, increasing the risk of flooding on other side of the river bank and downstream.

In the case of Uttarakhand, development and deforestation are attributed to the flooding hazard. The exceedance of tourism carrying capacity, flood plain conversion for construction of multi-storied structures at the ecologically fragile river beds and promotion of forest based industries that increased consumption from the forests are a few of the major anthropogenic causes. The building of hydropower dams and unscientific construction methods followed on flood plains and hill slopes to cater to the tourist trails have further increased the risk of flood and landslides. The non-removal of landslide debris also causes flooding in the regions.

In the case of Mumbai, encroachment of the natural drainage channels on either side by real estate and the sprawl of slums have reduced the channel width and the floodway path overlaps with the high density socio-economically vulnerable settlements. The region has lost about 40% of mangroves between 1995 and 2005. The natural stormwater drainage provided by the rivers flowing through the city is hindered by waste dumped on the river channels [16]. Concrete retaining walls provided as a structural measure against the flood increase the velocity of the flow downstream thus increasing the devastation.

In Chennai, the topographical flatness of terrain and filling up of natural and manmade water bodies, clogging of existing canals and rivers with ineffective drainage facilities and high surface runoff are the major causes that have aggravated the situation of flood. Construction of transport network along the major water-courses, decrease in open spaces and green spaces along with the outdated sewage system are few of the other causes.

2.2 Lessons Learnt and Possible Adaptations

Bihar State Disaster management authority has a well-developed hazard mapping done for the state [8]. Uttarakhand flood plain zoning Act 2012 is the guidelines for flood plain zoning. Hazard zone maps are also available for the region [15]. Prohibited area and other restriction are provided in the Act but flood plain delineation are not specified with respect to distance from rivers. Measures that need to be taken regarding the existing urban areas is not specified. Mumbai disaster management plan defines and demarcates certain environmentally sensitive lands such as marshy lands along the creek, hilly areas, agricultural lands, high tide areas and barren lands and some lands under primary activity as No Development zone [16]. From the study of these regions, relationship between land use followed and its influence in context of climate change was derived.

In Bihar major adaptation followed are maintaining levees and also providing emergency mitigation measures during and after flood. A complete halting of developmental activities without an environmental impact assessment was declared after the major Uttarakhand flood of 2013. In Mumbai developable areas as well as protected areas are delineated in the metropolitan master plan while there are no measures for riverside urbanization. River bed cleaning and removal of debris is progressing. In Chennai, linking drainage channels and cleaning and aligning existing ones are being done as part of Smart City mission.

The levees have aggravated the situation by increasing river velocity, reducing drainage options and hindering the fertile quality of flood plain. It was found that dams can prevent floods only to an extent. Current embankments constructed without holistic watershed approach have caused more issues than they intended to solve. Instability of Himalayan ranges is underestimated. Flood plain conversion and construction on river bed aggravated the vulnerability of the region. Unsuitable land use practices like deforestation, tourist trails at highlands increase the landslide risk. Regulation of flood plain through river bed protection, de-siltation and scientific muck deposition after flooding need to be adopted. Scientific slope stabilization is thus required. Building foundation needs to be stabilized. Managing existing water bodies and reviving lost ones need to be done appropriately. Uncontrolled sprawling is a threat to resilience of the urban area. From the literature review, it is realized that the risks faced by these regions are more anthropogenic than climatic or natural factors.

2.3 Global Adaptations and Best Practices

A global understanding of the adaptations and challenges followed in different parts of the world provided a perspective for identifying best practices. In case of Japan, to prevent disorderly urbanization the regions were divided as Urbanization Promotion areas (UPA) and Urbanization Control Areas (UCA). Tax incentives for maintaining agricultural land in urbanizable areas are in place. Categories for zoning are fixed such that all regions are not to be equally developed, this means regulations do not apply equally but are based on a rationale that applies to the area. Through this regulatory process, controlled mixed use is promoted with respect to the major characteristic trait of the regions, e.g.; Fire protection zone, Quasi fire protection zone, Parking place development district, Port district, Productive greenery district and Historical townscape preservation district [17, 18].

In the case of the Netherlands where a quarter of the county's land area lies below the mean sea level, initially had concentrated on structural measures like barriers, dams, groynes, floodwalls and similar defensive infrastructural strategies to help them manage the frequent flooding. Currently, there has been a shift in their approach from defensive to accommodative. The importance of Water Management Plan in association with land use is realized. Wetland cultivation through reclamation, Room for the river, by widening river banks, lowering of flood plains, distributing the overflow of river by preparing a portion of land for flood impact and encouraging society to embrace living in waterfront and urban water environment are few of the measures that have helped in the long run [19]. Active planning rather than passive planning is adopted by the government or local administration as initiative (including accumulating land, envisioning, planning) is taken up by the government rather than waiting for private initiative and influencing those with regulations.

Canada being a country, with diverse characteristics of local regional landscape address specific issues in each province through a decentralized system of climate change adaptation [20]. There are various specialized plans and other land use planning-decision-support tools like official plans, local plans on special matters, zoning, land subdivision and development controls, covenants and easements, design guidelines, environmental review of development projects and assessments of community vulnerability and risk.

Keene, in the United State of America, focus on working with local governments for sustainability and thereby developed a Climate Adaptation Action Plan in 2007. Such progress at lower levels of administrative hierarchy provides accurate details and inputs for the most suitable and practical adaptation plans [21]. Three areas are in focus, built environment, natural environment and social environment. In the City of Kansas in the USA, there is a limit on development of approximately 12% of the city's undeveloped land, 8% of which lies in the 100-year flood plain and an additional 41% of which will be preserved as permanent open space [22]. Along with an overflow control plan [22], developers must submit stream buffer plans for projects where the stream setback ordinance is in effect [23]. Many aspects of the ordinance use smart growth strategies, including density bonuses, smaller lot sizes and flexible design standards [23].

3 Discussion

The four pivotal factors that shape the land use and its subsequent flood risk are population, geographical constraints, developmental urbanization and governance. Impact of population can be understood in terms of demography, social factors and cultural factors. Regional geographical limitation can be understood in terms of sensitivity and neighboring risk. Developmental urbanization can be understood in terms of economic activity and global factors. Governance can be understood in terms of governance model and its efficiency (see Fig. 1). These factors has major spatial repercussions. The interaction between land, humans and urban settlement was evident which showed lack of respect to the contextual capacity of the region and the ill management of the resources are the root cause for all the negative impacts

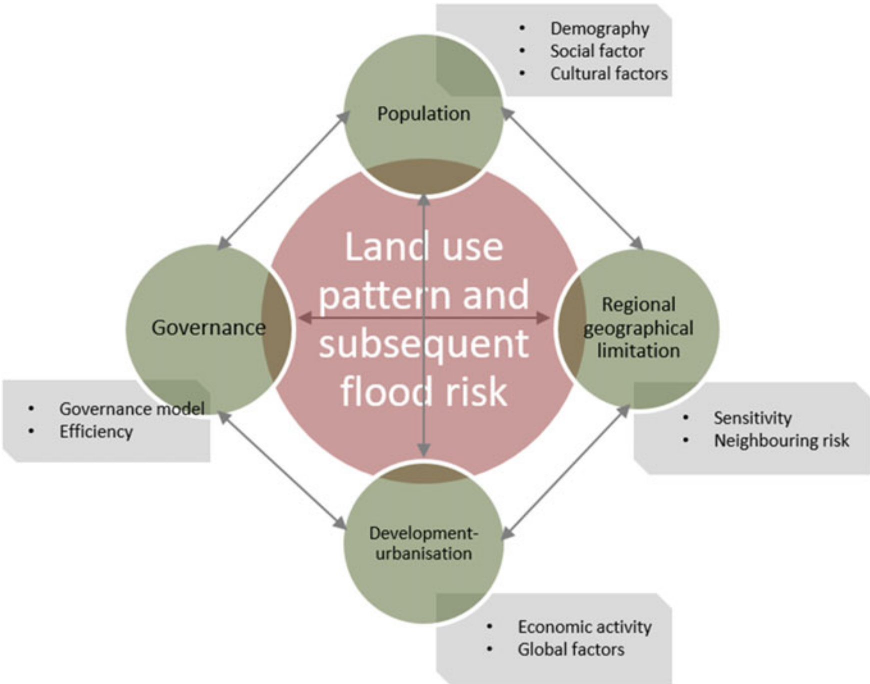

Fig. 1 Primary factors with spatial repercussions

other than the extrinsic factors of climate change over which our regional control is minimum.

The concepts and quantifying mechanism of carrying capacity and ecological management tools were identified as possible approaches with which the four factors can be quantified and managed. The carrying capacity of an area is the maximum number of people that can be supported by the environment in an eco-friendly manner utilizing the available resources. Ecological management practices provide nature-based solutions for reducing flood risks in a sustainable and economically viable manner [24].

Constraints for ecological management practice, especially in a developing nation include limited land availability, data scarcity and limited funding. In an urban setting, ecological management practice cannot be optimally implemented ideally. The tradeoff between urban development and flood control measures is thus important for policy and decision makers. To address these restrictions watershed management through land use optimization and cost optimization-through cost–benefit analysis is beneficial [25].

Four major conclusions were drawn from the cases of Japan, Netherlands, Canada and the USA to arrive at areas that need focus. The first focus is on controlling urbanization. This can be achieved by designating areas that specifically promote urbanization and where urbanization need to be controlled. Promotion of mixed use zoning with respect to the major characteristic of the region intended for densification, for example, special district zoning can help in setting priorities for each region. The second focus is on eco-sensitive planning which intends to incorporate climate change projections and scenario planning in all developmental projects. It also involves identification of flood plains-yearly, 5 years, 10 years, 25 years, 50 years, 200 years, wetland conservation, blue-green infrastructure planning and other non-structural measures. The third focus is on developmental regulations. Regulations like stream ordinance where the developer must submit stream ordinance buffer plans for a project where stream ordinance is in effect can be useful. Low impact development in flood plains that encourage urban water environment can help in inducing better land use practices. Local bodies can customize these plans with state/National guidance with required flexibility as needed according to context. The fourth focus is on fund facilitation whereby climate financing is utilized through various policies that involve ‘No regret Policy’ which is cost-effective climate finance that focuses on implementing pending developmental services in a climate adaptive manner. An approach of ‘active planning’ can be followed whereby the first initiative is taken by the local administration, rather than trying to influence an initiative taken by others. Value capturing is another mechanism that will prove useful. Incentives in taxation could be used that encourages non-conversion of productive farmland (and conversion of unproductive farmland to productive) in urbanization promotion areas.

3.1 *Towards Resilient Sustainable Landuse Planning Approach (RSLUP)*

In order to implement RSLUP approach, there is a need for adopting a concentric approach for analysing the situation as well as implementating the planning solution. The two approaches are bidirectional (see Fig. 2). The first and the all-inclusive approach is the regional approach, which includes scenario analysis in terms of ratio, comparisons and co-relations using the inputs of LULC at the large regional scale to understand the regional setting. The interaction between upstream and downstream land areas need to be studied by analyzing the regional scale watershed. The second approach is area based approach. This approach looks at the contextual and community level flood plain mapping. It can also decode the urban developmental interventions required, building codes, landscape treatment, land utilization. Further carrying capacity implementation can be done at administration level (see Fig. 3).

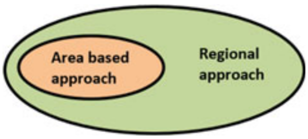

Fig. 2 Regional-area approach

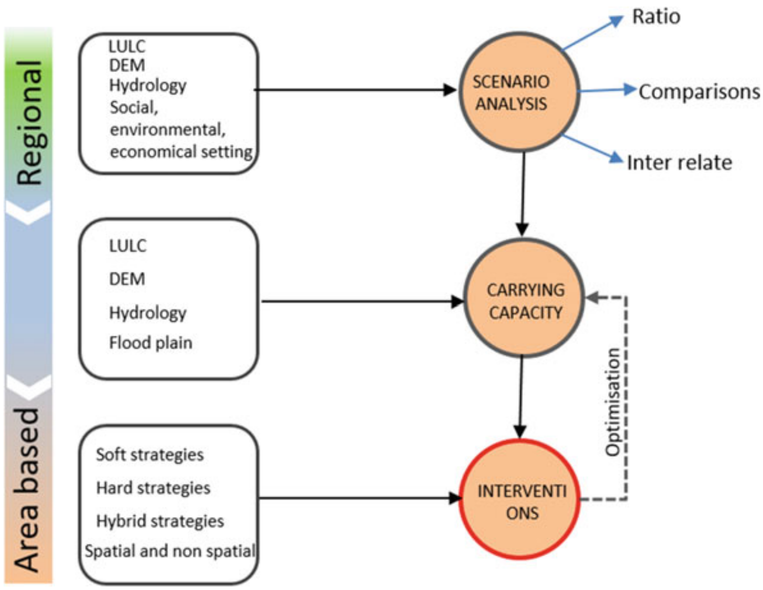

Fig. 3 Structure for an RSLUP

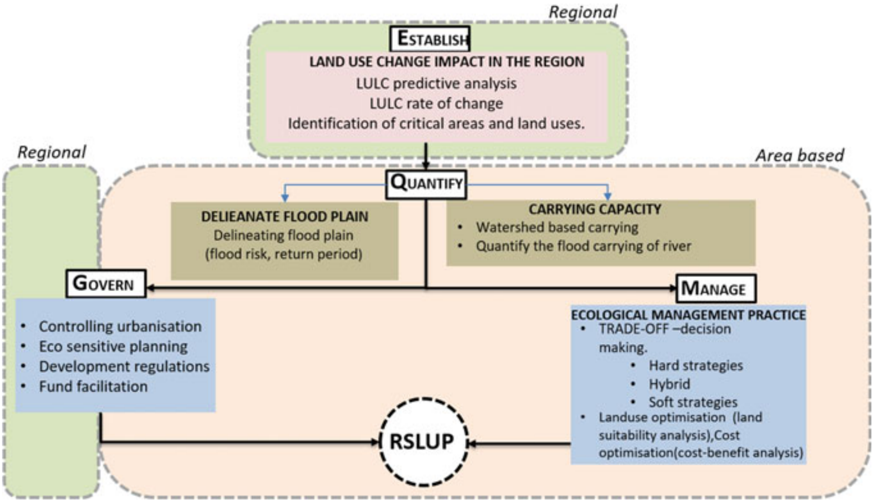

Fig. 4 EQMG approach for RSLUP

A feedback mechanism is needed to be introduced into this approach to validate the process.

3.2 The EQMG (Establish, Quantify, Manage and Govern) Pathway for RSLUP

From the above literature review and from the case studies of best practices a four step approach is derived (see Fig. 4). The approach consists of multiple paths that can lead to resilient sustainable land use planning (RSLUP). Both regional and area based approach is used. The first step in this pathway is to establish: land use change impact in the region. This includes LULC predictive analysis, LULC rate of change, identification of critical areas and land uses. The second step in the path is quantification. This includes delineation of flood plain, in terms of flood risk and return period, quantifying carrying capacity based on watershed and quantifying the flood-carrying capacity of the river. Governance and management are very important part of the process. Governance includes controlling urbanization, eco-sensitive planning, development regulations and fund facilitation. Management includes ecological management practices, decision making on trade-off points based on hard strategies, hybrid and soft strategies, land use optimization (land suitability analysis) and cost optimization (cost-benefit analysis).

4 Conclusion

Land use planning is the key to resilience and sustainable urban development. The need for land use planning reveal the interdependency of factors that needs to be managed effectively. This calls for quantification and threshold analysis by means of carrying capacity analysis and ecological management plan. These have to be optimized using suitable land optimization and cost optimization methods for the proposals to be implementable and feasible. Best practices of resilience adaptation related to land use planning in a global context provided the basis for sorting out a suitable approach. Further, a pathway was developed using the management criteria and approach identified as EQMG for RSLUP (establish, quantify, manage and govern for resilient sustainable landuse planning). This can be applied as a guiding approach for analysing the existing interaction of built-up regions and watershed and thereby lead the path for developing resilient sustainable landuse. Future studies can utilize the pathway created and replicate in contextual scenarios which can form an important analysis tool for policymakers.

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Resilient City and Flooding

Identification of Risks in the Water Conduction Infrastructure for Supply Systems, a Strategy to Increase Resilience

Y. Sánchez, Y. Rodríguez, and H. Díaz

Abstract The management and operation of urban drinking water systems are subjected to risks that endanger the sustainability and quality of the service. The risk analysis must be focused on damages to the demand or tentative negative consequences for the health and wellbeing of users. The challenges will require sustainable and proactive solutions for adaptation to Climate Change and disaster risk reduction. The water supply infrastructure is particularly vulnerable due to its role in the satisfaction, quality, and quantity of the demand. In this regard, the drinking water conduction infrastructure managed by Aguas de La Habana has been affected by natural, technological, and health events that have resulted in a crisis of the safety of the city's supply. It is proposed, as the main objective of the research, to create a methodology to identify and evaluate the risks in the water conduction infrastructure in supply systems. Associated events and hazards for conduction infrastructures are identified. Associated with the methodology, the Expert Survey is proposed to identify and assess risks in the main conduction systems of management companies in Cuba.

Keywords Risks · Water conduction · Supply systems · Resilience

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1 Introductions

It is important to rethink the way in which water and sanitation services are managed, for which a resilience approach that considers natural and structural threats must be included [9]. The risk function gives an important measure of the safety loss that a system may have due to a certain event [11].

Risk management is the process of identifying, analyzing, and responding to risk factors for the benefit of the sustainability of a system. The water conduction stage is particularly vulnerable due to three fundamental aspects: adequacy of infrastructure, lack of monitoring, and inadequate management policies [10].

The Civil Defense (DC, according to its acronym in Spanish) in Cuba develops hazard, vulnerability, and risk studies (PVR, according to its acronym in Spanish) for disaster situations, in coordination with local governments [3]. Decree-Law No. 170 of the Civil Defense Measures System and Resolution No. 4/2017 have strengthened the effort and support in this regard [8].

The DC has established the obligation for government institutions to prepare their own risk studies at smaller scales [3]. In this regard, Aguas de La Habana dynamically updates the Civil Defense Folder of the Disaster Reduction Plan. The plan constitutes a methodological guide to reduce vulnerabilities and minimize the effects of risks based on coordinated and preventive work.

Despite the methodological and dynamic work carried out in Aguas de La Habana, the growing impact of catastrophic events has endangered the quality and continuity of the water service to the city. In the case of water conduction, Havana has important lines that ensure the supply and are exposed to different hazardous events.

Different events have catastrophically impacted the safety of the supply. Risk management does not seek to eliminate all vulnerabilities since it would be uneconomical in many cases. Instead, it intends to anticipate impacts and study coping alternatives that increase resilience capacity. The initial stage of sustainable risk management is linked to its identification and evaluation.

General objective

To create a methodology for the identification and evaluation of risks associated with the conduction of water in supply systems.

Specific objectives:

To define hazardous events and hazards associated with the conduction of water in supply systems.

To propose the methodological bases for the identification and evaluation of risks associated with the conduction of water in supply systems.

2 Methods

The Civil Defense (DC) in Cuba adopted the terminology of the United Nations International Strategy for Disaster Reduction (UNISDR) to the national context. This was done under the consensus of including new terms that are key for the understanding and materialization of experiences in disaster risk reduction [4].

Risk management in Cuba consists of a four-stage cycle: prevention, preparations, response, and recovery [4]. Each of these stages has proactive management at its center, as a key element for reducing damage and prejudice to the economy and society. In the urban water cycle, these four stages are maintained as part of a strategy aimed at increasing the sustainability of water and sanitation systems.

Keeping in mind the regulatory and normative framework, as well as the studies of Hazard, Vulnerability, and Risk, on the basis of the described methodology, a study is being conducted to evaluate the risks during the conduction of water for the consumption in the Central System- Havana. The system is supplied having Nudo de Palatino as a starting point, to which the lines of Cuenca Sur and Vento Channel arrive (see Fig. 1).

The Central System-Havana has an associated population of 732,330 inhabitants. In its urban environment, there are important health centers, industrial polygons, as well as economic and socio-cultural entities of great importance for the city. All

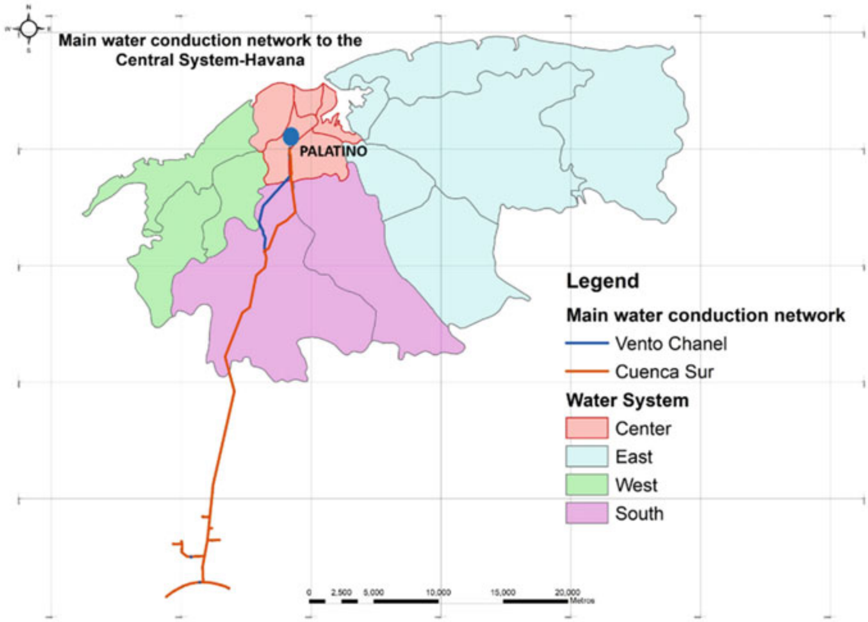

Fig. 1 Central system conductions: Cuenca Sur and Vento Channel. *Source* GIS, Aguas de La Habana

along their route, both systems are exposed to different types of dangerous events that put at risk the security of the supply of the Central System.

Cuenca Sur is active since 1959. It is a pipe of concrete- steel center of 1950 mm of diameter with a longitude of 36 km. Its maximum conduction capacity is 3600 l/s. Vento Channel is a masterly work constructed in 1893. Due to its heritage and technical values, it is considered to be one of the seven Wonders of Civil Engineering in Cuba. The Channel has an ovoid shape and was built with quarried stone. It has a slope of 1:5000 and a length of 9 km. Its maximum conduction capacity is 2872 1/s.

As part of prevention, risks are identified and evaluated according to their level of criticality. Preparations give way to a stage of investments, creation of resilience capabilities, and mitigation strategies. The response is the stage where the action plan is executed to maintain basic levels of water and sanitation, as well as to provide direct and transparent information to decision-makers and the general public. During recovery, resilient capacities are validated and risks are reexamined to update the management plan.

Risk is a direct function of the probability of occurrence and its consequences, and the management itself is formulated as a result of Eq. 1 [1]:

$$\text{Risk} = \frac{\text{Hazard*Vulnerability*Exposure}}{\text{Resilience}} \tag{1}$$

The main risk concepts in urban water systems [1] are aligned with the strategy of the DC:

Disaster: Loss of functionality or restricted access to drinking water and sanitation services.

Threat: It can be unique, sequential, or combined in its origin and its effect. Each hazard is characterized by its location, intensity or magnitude, frequency, and probability.

Vulnerability: They can present their own vulnerability due to the lack of risk analysis, design, planning, programming, use, and maintenance.

Exposure: It determines the predisposition of the component or subcomponent of the urban system, as well as its susceptibility and exposure to the negative impact of a destructive phenomenon.

Risk: It is a function of the latent probability of an event occurring that produces certain effects, the combination of the probability of the occurrence of an event, and the magnitude of the impact that can cause f (probability of occurrence, consequence).

In recent decades, the traditional definition of resilience has been enriched so that a system, when faced with an adverse situation, in addition to having the capacity to recover, maintains an adequate performance in terms of service, coverage, economy, etc. [2, 5, 6].

The risks in the conduction of water will be grouped in: natural, technological and sanitary, to be coherent with the national strategies [3]. Based on a bibliographical analysis [1, 3, 7, 10, 12] the diagram of classification of risks associated with the conduction of water in supply systems is presented (see Fig. 2).

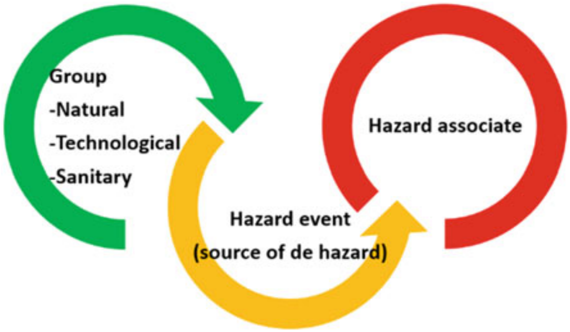

Fig. 2 Classification of risks associated with the conduction of water in supply systems. *Source* Own elaboration

The risk commented in Eq. 1 will depend on the identified hazard, the vulnerability, the exposure, and the resilience. The last three characteristics depend on the infrastructure, that is, its level of exploitation, operation, maintenance, as well as of socio-economic and environmental aspects. Each one of the variables that compose the function risk, will be based on the probability and the consequence for the continuity of the supply for the conduction system in question.

Considering the methodologies consulted [1, 3, 7, 10–12], the events and hazards associated with the stage of conduction of water in supply systems can be identified, in a first approach, in the Table 1.

The identification of events and associated hazards expressed in Table 1 will be particularized for the conduction system subjected to a risk management plan. Taking into account the historical events and the expert criteria, without there being a regular function for each system, the proposed ones should be examined and new ones suggested if so considered.

3 Results

The methodological process has the purpose of evaluating the risks that compromise the safe continuity of the supply in terms of quantity or quality. A cyclical system, nurtured by the re-evaluation of present risks and the identification of new ones, guarantees the strengthening of resilient capacities. Figure 3 shows the methodology to be followed for the identification and evaluation of risks in supply water conduction systems, as a result of the adaptation, to the national context, of studies and international methodologies indexed in the investigation.

Based on the evaluation, proactive risk management of the risk would begin looking for solutions that minimize, up to where it is economically possible, its negative effect on the continuity of the supply. Within the two stages mentioned (Identification and Evaluation), tasks that complement one another are defined.

To ensure that new events, and the dangers associated with them, are considered, the team of experts will periodically review the conduction system on the basis of the

Table 1 Events and hazards associated with the stage of conduction of water in supply systems

Class	Hazardous event (source of danger)	Associated hazards									
		Partial/Total damages of pipelines	Partial/Total damages of elements of the pipelines	Damage in the quality of the water	Communication failure	Loss of the automatic control	Damage to the inspection capacity	Control Loss	Water hammer	Demand increase (not authorized)	Demand increase (for exceptional situation)
Natural	Tropical hurricanes	*	*	*	*	*					
	Intense rains	*	*	*	*	*					
	Severe local storms	*	*	*	*	*					
	Penetrations of the sea			*	*	*					
	Landslide	*	*	*	*	*					
	Fires in rural areas	*	*								
	Earthquakes	*	*	*	*	*					
	Electric storms	*	*	*	*	*					
	Intense drought	*									
Technological	Water loss	*		*							
	Collapses of constructions						*				
	Urbanization						*			*	*
	Telemetry				*			*	*	*	

(continued)

Table 1 (continued)

Class	Hazardous event (source of danger)	Associated hazards									
		Partial/Total damages of pipelines	Partial/Total damages of elements of the pipelines	Damage in the quality of the water	Communication failure	Loss of the automatic control	Damage to the inspection capacity	Control Loss	Water hammer	Demand increase (not authorized)	Demand increase (for exceptional situation)
	Failure of the instrumentation							*	*	*	
	Power cut				*			*	*		
	Fluctuation of pressure							*	*	*	
	Intermittence of water supply			*					*	*	
	Operation of valves				*			*	*	*	
	Unauthorized connections			*							
Sanitary	Vandalism	*	*	*	*	*					
	Interruption of the Treatment			*							
	Contamination of the supply source	*	*	*							
	Spills of chemical substances (Hydrocarbons, etc.)	*	*	*							
	Pandemics									*	*

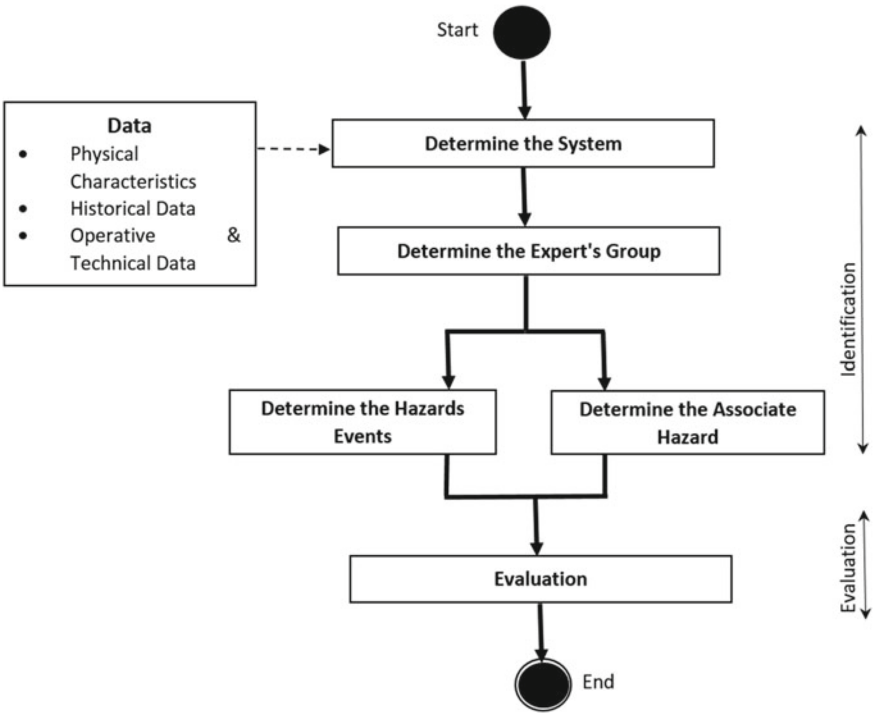

Fig. 3 Methodology for the identification and evaluation of risks in the conduction of water in supply systems. *Source* Own elaboration

outlined methodology. A particular advantage of the methodological application with the consequent risk management will result in a possible reduction of the number and seriousness of the incidents, as well as of the emergency situations or quasi emergencies.

Besides the periodic exam, it is important that the system is reviewed after each emergency, incident, or accidental event, independently of whether new dangers were detected or not. A post-incident exam will detect aspects that can be improved, either a new danger or the modification of the degree of risk in its evaluation. To guarantee the capture of historical events, corporate-scale procedures will have to be designed.

Based on the execution of the described methodological stages, an effective plan of risk management could be started. It becomes necessary to evaluate the methodological result when there is an intervention in risk or a new one appears.

The methodology is in the implementation stage, although its development behaves in a dynamic way to guarantee the examination of new hazardous events. The identification of hazardous events and associated hazards bear intense work on the part of the experts. The form makes reference to the results obtained in Table 2, as initial suggestions for experts.

Table 2 Matrix for the classification of risks

		Consequence for the continuity and quality of the supply				
		Insignificant (1)	Minor (2)	Moderate (3)	High (4)	Catastrophic (5)
Probability/ Frequency	Very high/Once a day (5)	5	10	15	20	25
	High/Once per week (4)	4	8	12	16	20
	Moderate/Once a month (3)	3	6	9	12	15
	Low/Once a year (2)	2	4	6	8	10
	Very Low/Once every 5 years (1)	1	2	3	4	5
Punctuation of the Risk		<6	6–9	10–15	>15	
Classification of the Risk		Low	Medium	High	Very high	
Probability × Consequence						

Source Adapted from WHO & IWA, 2009 and Arteaga D. & Ordóñez J., 2019

The evaluation provides an image of the system that is "frozen in the time", a reason why it should be reconsidered periodically to avoid missing new dangers. Each one of the variables that compose the function risk (threat, vulnerability, exposure, and resilience) will be based on the probability and the consequence for the continuity of the supply for the conduction system in question. The classification of the variables will be given on the basis of the following evaluation:

- Low
- Medium
- High
- Very high

Based on the aforementioned, the matrix shown in Table 2 is used for the classification of risks:

The matrix presented in Table 2 shall be evaluated for each one of the elements of Eq. 1 to finally make a multicriteria weighing and define the matrix evaluation giving priority to the risks of greater impact.

The probability and frequency, subject to the consequence for the continuity and quality of the satisfaction of the demand, define the consequences. The events and hazards are identified by experts and shall be reexamined in a dynamic way by means of methodological procedures. The evaluation provides an image of the system that is "frozen in the time", reason why it should be reconsidered periodically to avoid missing new hazards.

4 Conclusions

1. The risk function is defined according to the occurrence probability and its consequences keeping in mind the hazard, vulnerability, exhibition, and capacity of resilience of the system.
2. Hazardous events are classified according to their nature and origin as: Natural, Technological, and Sanitary, as established by the Civil Defense in Cuba.
3. The evaluation of risks associated with the conduction of water in supply systems will be evaluated in four levels: Low, Medium, High, and Very High.
4. The proposed methodology, obtained from technical, operative, and aqueducts management peculiarities in Cuba, will be evaluated on the basis of the occurrence of new events and the periodic revision of the system.

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A State-of-the-Art Review on the Unique Characteristics, Key Driving Causes and Mitigation Measures of the World Catastrophic Flood Disasters

K. Y. Lim and K. Y. Foo

Abstract Floods are the most frequent and lethal natural disasters, accounting for approximately 40% of the natural hazards around the world. The diverse characteristics, frequency, magnitude, causes and impacts of the sudden flooding could be largely affected by the unique physical geographical elements, population distribution patterns, socio-economic status, land uses, river training and hydrometeorological dynamics. In the course of history, the diachronic flood events over the past 20 years have brought miseries to approximately 4.2 billion of victims, inflicting the total estimated global economic damages of US$ 2.97 trillion, with 1.23 million of reported deaths and missing. The high pressure of floodwater is incredibly strong to destroy levees, water treatment plants and disposal-sewage systems, to disseminate the organic and inorganic pollutants, nutrients, toxic and hazardous chemicals and feces from the residential, urban, agricultural and industrial zones into the nearby natural aquatic systems, especially in the case of episodic rainfall. The large-scale contamination of floodwater in the local depression has greatly magnified the risks of developing numerous acute and chronic water-borne illnesses, which is associated with inadequate clean water resources, and sanitation and hygiene practice during the extreme flood tragedies. The study of flood dynamics and their triggers are the key issues on disaster risk reduction in building a disaster resilient society, while the retrieval of the compilation of historical flood data in different regions of the world is still limited and not-updated. In this sense, the present work postulates the initial platform to provide a concise and comprehensive information on the evolution of historical flood events recorded in each continent of the world since nineteenth century. The definitions, sources and major causes of flood-related events will be critically presented, and the particularities of the situation, driven by the severe historical flood tragedies will be documented. The changing characteristics of floods with different generation mechanisms will be briefly discussed. Moreover, a complementary set of structural and non-structural measures, which have brought both beneficial and detrimental changes in the hydrography and ecology of riverine environments will be elucidated.

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1 Introduction

Flood disaster, a complex multi-interplay between the atmospheric, geologic and hydrologic processes, is an extreme water-related weather event. The probability and severity of floods are driven by the multiplicity of natural and spatial or temporal variabilities of meteorology, topography, soil, vegetation, climate change and the channel drainage systems (Fig. 1). According to the Intergovernmental Panel on Climate Change (IPCC) [1], the earth's surface is growing warmer than any preceding decade since 1850, forecasting an increase in the global surface temperature of 1.5–2.0 °C by the year of 2100. The most recent report on weather and climate extremes by the Emergency Event Database (EM-DAT) [2] also recorded 72.1% increase or 5297 of new hydrometeorological natural events, specifically floods, flash floods, tsunamis and storms, that have brough miseries to approximately 4.2 billion of the population, to inflict the annual economic damages of exceeding US$ 2.97 trillion, with more than 1.23 million deaths over the last 20 years (2000–2019).

Statistically, approximately 21 million people are affected by the river floods annually, dominated by India, Bangladesh, China, Vietnam, Pakistan, Indonesia, Egypt, Myanmar, Afghanistan, Nigeria, Brazil, Thailand, Democratic Republic of Congo, Iraq and Cambodia, accounting for 80% of the total affected victims [3]. These

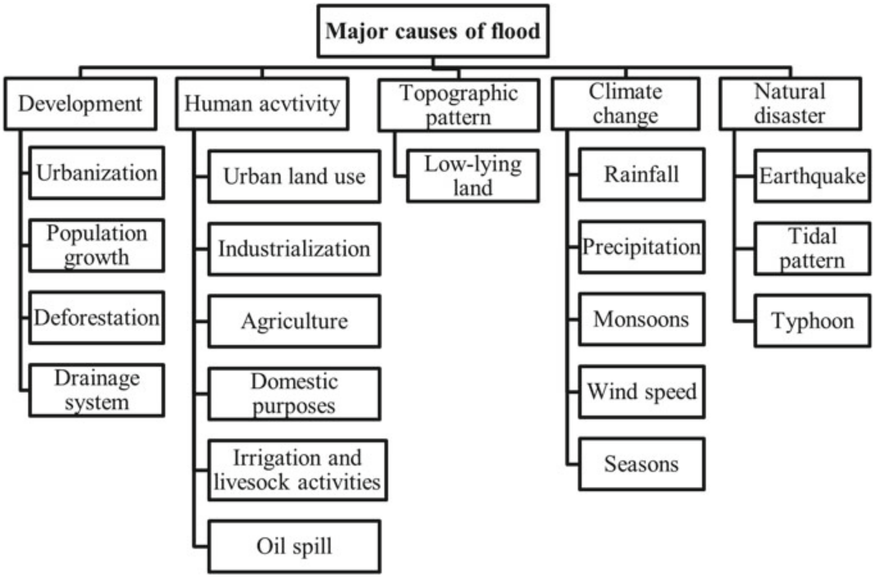

Fig. 1 Major causes of flood events

rising incidents are related to the limitations of the existing flood disaster management plans and preparedness, notably the improper execution of traditional structural measures, implementation of legislative regulations and controlling schemes, end-to-end management and awareness programs. Within the aforementioned, the present work was oriented (a) to highlight the definition, changing characteristics, mechanisms and types of flood events, (b) to provide a concise and up-to-date overview of the historical series of flood events in every continent of the world, and (c) to summarize the structural and non-structural strategies in the flood mitigation technologies.

2 Flood

2.1 Definitions, Characteristics and Major Causes of Flood

Flood is a manifestation of extreme water flow and level in a river system, where an area lying near to the large water bodies is inundated and damaged by high water stages, to induce significant changes in the floodplains. It is defined as an event triggered by the prolonged-period of excessive rains, snow-melt, short-term intense precipitation or tropical cyclonic storms system coming ashore, driven by the rapid urbanization, poor-quality drainage facilities or waste accumulation or deterioration of waterway channels by excessive land-clearance activities [4].

There are different contexts and categorizations pertaining to flooding, including storm surge, tsunami, monsoon flood, cyclonic flood, regular flood, artificial flood, flash flood, river flood and coastal flood events. However, they are not similar as some of them can develop slowly during an extended period of continuous rain, while the rest can occur quickly even without any visible signs of precipitation. Figure 2 illustrates different types of flood and the generating mechanisms.

Monsoon flood	**Cryospheric flood**	**Geological flood**	**Hybrid flood**
• Torrential rain • Cloud burst	• Glacial lake outburst flood • Glacier surge dam burst flood • Storm surge • Hurricane • Tropical cyclone • Tsunami • Tornado	• Landslide dam outburst flood • Riverine flood • Flash flood • Debris flood • Coastal flood • Urban flood	• Rain on snow • Rain over glacial lake • Ice-jam flood

Fig. 2 Different types of flood generating mechanisms

Floods could be defined as with the chance of lesser than 0.001, despite of climate change is playing a significant effect in global warming, enhanced greenhouse gas emissions, rapid snowmelt, higher-intensity hurricanes, prolonged rainfalls, sea-level rise, intense convection storms and typhoons, that is consistent with the recent reported works [5, 6]. According to the Intergovernmental Panel on Climate Change's Fourth Assessment Report [7], changes in the frequency of intense storm surge events and precipitation are the major driving forces behind flood hazards, that have enhanced the severity of flood phenomena, and these factors are expected to be amplified in the near future, especially in the middle latitudes and Asian monsoon regions.

According to the thermodynamic concepts, it could be deduced that the rising temperature will intensify the alteration of hydrological events, evaporation, evapotranspiration and precipitation rates. Together with the shifting climate zones and a strong increase in the convective processes, the rising frequency or severity of the weather-related events in different regions of the world could be anticipated. This could be evidenced by a greater frequency and magnitude of high flow in the United Kingdom for the last 30–50 years [8]. A rising temperature by greater than 1.3 °C has also been documented in Canada since 1948, two times above the average temperature, and it is generally humid, with the average precipitation rate of above 12%, leading to an advancement of the river flow condition [9].

Morphological changes driven by the human land use activities, including deforestation, agricultural development, industrialization and urbanization, to remove the green spaces, reduce the water absorption capacity and enhance the surface runoff, are synergies to the probability and severity of flood risks. With respect to the urbanized watershed, a large proportion of impervious land use types, low vegetation cover and high-density drainage systems have seriously affected the retention of stormwater, and eventually fasten the urban runoff, to induce a greater velocity and rapid flood peaks. According to Avashia and Garg [10], the high-water levels in rivers due to highly impervious watersheds at the upstream areas, have altered the conveyance capacity of sewer pipes, and produced localized flooding in some urban areas, even during short and intense rainfall events. The rising population density in the flood-prone coastal zones and megacities is expected to influence the frequency and severity of large-scale floods by increasing the annual discharge of 10% [11]. Over-urbanization has evidently led to a wide range of flood-related problems, notably long-term land subsidence in a large number of China's cities [12], and the Netherlands [13], which is associated with the sea level rise and higher river flows from ice melt, and greater population growth in Australia [14].

2.2 Historical Flood Tragedies According to Different Regions

Unusually severe floods since 1500s have affected much of the regions in the world (Table 1). In Africa, natural hazards, notably in the forms of flash flood, urban flood, river flood and coastal flood, recorded the highest events. The historical flood disasters in Nigeria could be traced back to the 1963 flood event in Ibadan city, when the Ogunpa River was overflowed to cause critical property damages and health implications. The capital losses and deaths exceeded US$ 83 million and 100 people, respectively, were recorded in 1978, 1980 and 2011 [15]. According to the International Disaster Database on Nigeria Disaster, the worst but recent flood event in 2012 alone, had killed 363 people, and displaced 7,000,867 lives, with the total economic losses of US$ 7.228 billion [16].

Similar historical records devoted to different extreme weather-related disasters have been documented in the continental United States of America (USA) since early 1850s. From 1996 to 2017, the Canadian Disaster Database [17] indicated that flood remains the most general disaster events in Canada, resulting in 169 flood tragedies, with the damages surpassing US$ 30 million, mainly governed by hydrometeorological factors, topography, population dynamics, land use changes, thermodynamic conditions and large-scale cyclonic circulations. The outstanding example in the America region is the 1993 Great Flood in the upper Mississippi and lower Missouri river systems, to cause an unprecedented loss of US$ 18.1 billion and 52 of fatalities [18], while Hurricane Mitch 1998 is one of the deadliest hurricanes in history, which had inundated 80% of the city of Trelew, with approximately 11,000 people were killed and more than 8000 were found missing [19]. The Hurricane Katrina's storm surge in 2005, was the worst disaster, and the Mississippi River Gulf Outlet has contributed to exceeding US$ 200 billion, and 1833 lives lost [20].

The same report stated that wide parts of the Central Europe, particularly Germany, Austria, Czech Republic, Poland, Hungary, Slovakia, Croatia, Serbia, Russia, Ukraine, Netherlands, France, Switzerland, Spain and United Kingdom, are heavily hit by unusual and large-scale flooding since 1600s. The floods within the central European are driven mainly by the interactions of large-scale lifting on the downstream trough system, orographically-induced lifting over the mountainous terrain, and embedded convection in the stratiform clouds, driven by prolonged and widespread heavy rainfall. The total economical loss within central Europe is estimated to be in the range of US$ 13–16 billion, with US$ 12 billion recorded in Germany. The intensity and frequency of flood disasters in Hungary is increasing, due to the agricultural development, deforestation, and improper regulations on the rivers and drainage management systems [21]. The Upper Tisza river basin in the Northeastern part of the country is one of the highest flood-risk area in Hungary, and one of the poorest regions in Europe. The flood of 2001, however, burst through the protective levees, has inundated 16,000 km^2 or 17% of Hungary, affecting approximately 17,000 people, and completely destroyed 3000 houses due to high speed of flood waves.

Flood tragedies in Oceania countries are usually induced by tropical cyclonic systems and population changes, particularly in the Northern regions. Rains and cyclones during the summer months (November–April) can be substantial, to cause large-scale flooding in the North-western tributaries, particularly Murray-Darling river system, which is the largest and longest river basin in Australia. A recorded-breaking flood in Warrego River during 1990 had seriously destroyed the rural area of Cunnamulla, which had submerged the Charleville town, of which all the commercial buildings, 80% or 1470 of residences, and many other homes were damaged and unlivable under 8.54 m of peak flood discharges, with the total estimated damage of US$ 316 million [22].

In Asia, the outburst flood events in the Himalayan-region (from Pakistan to Assam) for the past decades, have highlighted a greater flood prevalence, limitation of infrastructure setups or understanding on the flood forecasting and warning systems, and low disaster preparedness in the region. The 2010 flood event was the deadliest natural disaster to hit Pakistan in the recorded history since 1950, driven by monsoon rainfall and the simultaneous glacier melt, to affect 14–20 million victims, and killed over 1985. This flooding had last almost six months in some areas, with the total area of 159,999 km^2, and caused US$ 43 billion damages in 46 of the country's 135 districts [23].

Similarly, the destructive flood with gale-force winds had caused extensive damage in Kelantan, Malaysia as early as 1886. The flood event in 1926, supposedly the worst in Malaysian's memory, had affected most of the citizens in Peninsular Malaysia, with dramatic losses on properties, roads, farmlands and agricultural crops [24]. The catastrophic flood 1971 had affected many parts of Malaysia, and Pahang was drastically devastated, with the economic loss exceeding US$ 93.1 million, and a death toll of 85. The worst 2014 flood event, that took place at the East-coast (Kelantan, Terengganu and Pahang) and West-coast states (Perak and Johor) of Peninsular Malaysia, had suffered a great infrastructure damage of US$ 668 million, and affected 404,000 victims with 24 reported deaths and 8 are still missing [25].

Tropical cyclonic storm is the major flood contributor within the Bangladesh's history, and it affects the greatest aspects and populations. About 80% of the land is classified as a floodplain area, and as much as 34% of the land would be submerged under water for 5–7 months annually [26]. Among all, the 1998 flood was the worst in the history of Bangladesh, which had affected two-thirds (2/3) of the country, with the peak floodwater level of >20 m, resulting in 5338 deaths. In China, a catastrophe flood that struck the Yangtze River Basin during 1998 had covered an area of approximately 90,000 km^2 for more than 70 days, and affected 240 million citizens (3,656 casualties), with a total financial loss at US$ 30.7 billion. The 1931 flood event in Huang He River was the deadliest disasters in China, recorded an affected area of 109,000 km^2 along the river basin, and the highest death toll of 3.7 million.

Table 1 A historical summary of the documented flood events in the world

Continent	Year	Country (State/City)	Flood event	Affected population	Financial loss
Africa	2018	Kenya, Ethiopia, Uganda, Somalia, Djibouti, Burundi	HR	839,000; 500 deaths	US$ 215 million
	2015	Malawi	TS Chedza	230,000; 276 deaths	US$ 51 million
		Nigeria (Kebbi)	Flood	25,950; 5,495 deaths	US$ 570 million
		Nigeria (Sokoto, Zamfara)		24,750; 11 deaths	US$ 750 million
	2011	Mozambique, Zimbabwe, Namibia, Botswana, Zambia, Malawi	HR	19,000; 141 deaths	US$ 200 million
	2010	Benin	Flood	680,000; 50 deaths	US$ 5 million
		Niger, Ghana, Burkina Faso, Togo	TR	700,000; 138 deaths	US$ 673,131
	2009	Angola, Namibia, Zambia	HR	445,000; 131 deaths	US$ 5 million
		Niger, Ghana, Senegal, Guinea	HMR	940,000; 193 deaths	US$ 152 million
	2000	Mozambique	Cyclone Eline	44,000; 700 deaths	US$ 500 million
America	2017	United States (Texas, Houston)	Hurricane Harvey	30,000; 89 deaths	US$ 126.3 billion
	2013	Canada (Highwood, Red Deer, Little Bow, South Saskatchewan)	Alberta flood	100,000; 5 deaths	US$ 5 billion
	2012	Canada, Haiti, United States (New York, New Jersey, North Carolina)	Hurricane Sandy	233 deaths	US$ 78.8 billion
	2009	El Salvador (Usulutan, Cuscatlan), Bolivia (La Paz)	El Salvador flood	199 deaths	US$ 239 million
	2007	Mexican states of Tabasco and Chiapas	Tabasco flood	1,000,000	US$ 3.08 million
	2005	United States (Gulf Coast, Mississippi, Alabama, Florida Panhandle)	Hurricane Katrina	49,000; 1833 deaths	US$ 200 billion
	2004	Caribbean (Haiti)	Hurricane Jeanne	250,000; 5419 deaths	US$ 7.66 billion

(continued)

Table 1 (continued)

Continent	Year	Country (State/City)	Flood event	Affected population	Financial loss
	2003	United States of New Mexico (Santa Fe)	Flood	100,000; 154 deaths	US$ 1 billion
	1999	United States (South Carolina, Massachusetts)	Hurricane Floyd	2,600,000; 57 deaths	US$ 9.77 billion
		Gulf of Mexico	Tropical Depression Eleven	500,000; 636 deaths	US$ 491.3 million
		Venezuelan (Vargas State)	Flash flood	30,000 deaths	US$ 10 million
	1997	United States (North Dakota, Minnesota), Canada (Winnipeg)	Red River flood	50,000	US$ 3.5 billion
	1996	United States of Illinois (Illinois River)	Significant Illinois flood	3,400,000; 6 deaths	US$ 700 billion
		Canada (Saguenay-Lac-Saint-Jean region of Quebec)	Flash flood	16,000; 10 deaths	US$ 1 billion
	1993	Midwest of the United States	Mississippi flood	74,000; 52 deaths	US$ 18.1 billion
	1992	United States (Louisiana), Caribbean (Bahamas)	Hurricane Andrew	1,400,000; 48 deaths	US$ 26.5 billion
	1987	Canada (Island of Montreal)	Montreal flood	3 deaths	US$ 428 million
	1982	Brazil, Argentina, Bolivia	El Niño flood	600,000; 170 deaths	US$ 3 million
	1976	United States of Colorado	Big Thompson Canyon flood	144 deaths	US$ 156.3 million
	1972	Middle Atlantic United States	Hurricane Agnes	128 deaths	US$ 18.0 billion
	1946	United States (Hawaii, Alaska)	Pacific Tsunami	165 deaths	US$ 334.1 million
	1939	United States of California	TS	93 deaths	US$ 26.2 million
	1938	United States of California (Los Angeles)	Los Angeles flood	700 deaths	US$ 5.44 billion
	1937	United State (Pennsylvania, Ohio, West Virginia, Kentucky, Indiana, Illinois)	Ohio River flood	385 deaths	US$ 151.6 billion

(continued)

Table 1 (continued)

Continent	Year	Country (State/City)	Flood event	Affected population	Financial loss
	1928	United States of California (Los Angeles)	St. Francis Dam failure	200 deaths	US$ 291.8 million
	1927	United States (Arkansas, Mississippi, Louisiana)	Great flood	700,000; 246 deaths	US$ 41.7 billion
	1921	United States (Parts of Texas)	Texas flood	215 deaths	US$ 70.2 million
	1915	Canada (Edmonton)	North Saskatchewan River flood	2000	US$ 647 million
	1900	United States (Texas, Galveston)	Galveston Hurricane	12,000 deaths	US$ 602.3 million
Europe	2020	France (Fontpédrouse, Mont-Louis)	Storm Gloria	23,000; 14 deaths	US$ 200 million
	2018	Italy (Calabria, Sardinia)	Flash flood	26 deaths	US$ 245 million
	2014	Balkans (Bulgaria, Dobrich, Varna, Shumen)	Flash flood	16 deaths	US$ 381 million
	2013	Austria, Hungary, Poland	HR	1,300,000; 25 deaths	US$ 16 billion
	2012	Ireland	Great Britain/ Ireland flood	9 deaths	US$ 1.2 billion
		Russia (Krasnodar Krai)	Krasnodar Krai flood	30,000; 172 deaths	US$ 280 million
	2010	Slovenia (Ljubljana, Laško, Lower Carniola)	HR	3 deaths	US$ 18 million
	2009	Turkey (Istanbul, Tekirdağ)	Flash flood	31 deaths	US$ 214 million
	2000	Kent, Sussex, Shropshire, Yorkshire	Extratropical Cyclone	20 deaths	US$ 2 billion
	1997	Poland (River Odra and Vistula, Raciborz, Klodzko)	Summer flood	162,000; 54 deaths	US$ 4.5 billion
	1987	Italy (Valtellina)	Storm	53 deaths	US$ 2 billion
	1970	Balkans (Romania)	TR	240,000; 209 deaths	US$ 1 billion
	1957	Spain (Valencia)	Flash flood	81 deaths	US$ 19 million
	1952	Devon (Lynmouth), North Yorkshire (Middleham)	Lynmouth flood	1710; 34 deaths	> US$ 7 million
	1934	Poland	HR	55 deaths	US$ 12 million

(continued)

Table 1 (continued)

Continent	Year	Country (State/City)	Flood event	Affected population	Financial loss
Oceania	2019	Australia (Queensland, Townsville)	Monsoon flood	5 deaths	US$ 947,601
	2013	Australia (Queensland, New South Wales)	SS	6 deaths	US$ 2.52 billion
	2011	Australia (Queensland, Brisbane, Toowoomba)	Lockyer flood	200,000; 38 deaths	US$ 1.72 billion
	1986	Australia (Hawkesbury, Georges River)	TR	6 deaths	US$ 25 million
	1974	Australia (Brisbane)	Cyclone Wanda	14 deaths	US$ 49 million
	1955	Australia (Hunter valley, Castlereagh River)	Maitland flood	40,000; 24 deaths	US$ 130 million
Asia	2020	India (Andhra Pradesh, Telengana, Puducherry, Kerala, Goa, Maharashtra)	Deep depression BOB 02	98 deaths	US$ 681 million
		Vietnam (Cambodia, Laos)	Tropical depressions	189 deaths	US$ 1.52 billion
		China (Hunan, Guangxi, Guizhou, Sichuan, Hubei, Anhui, Zhejiang, Fujian, Yunnan)	HMR	744,000; 219 deaths	US$ 32 billion
	2019	India (Karnataka)	HMR	19,000; 61 deaths	US$ 4.95 billion
		Iran (Golestan, Fars, Khuzestan)	Flash flood	70 deaths	US$ 2.2 billion
	2018	India (Kerala)	HMR	1,247,496; 483 deaths	US$ 5.6 billion
		Japan (Shikoku, western Honshu)	Typhoon Prapiroon	225 deaths	US$ 9.86 billion
		Vietnam (Lao Cai, Ha Giang)	TS Son-Tinh	23 deaths	US$ 23.2 million
		Sri Lanka (Kelani Ganga, Gin Ganga, Nilwala Ganga)	Heavy southwest monsoon	698,289; 208 deaths	US$ 545,235
	2017	Malaysia (Terengganu, Kelantan)	HMR	25,525	US$ 1.5 billion
	2016	China (Areas along Yangtze and Huai Rivers)	HR	32,000,000; 499 deaths	US$ 22 billion
	2016	Malaysia (Sarawak, Johor, Negeri Sembilan)	HR	61,107; 3 deaths	US$ 550 million
	2015	India (Tamil Nadu, Puducherry, Andhra Pradesh)	2014–16 El Niño event	1,800,000; 500 deaths	US$ 14 billion

(continued)

Table 1 (continued)

Continent	Year	Country (State/City)	Flood event	Affected population	Financial loss
		Japan (North of Japan)	TS Etau	100,000; 7 deaths	US$ 97.8 million
		Indonesia (Aceh Jaya, Aceh Barat)	Monsoon rain	25,765	US$ 14 million
		Malaysia (Sabah, Sarawak)	HR	13,878; 1 death	US$ 1.03 billion
		Myanmar (Irrawaddy Delta, Magway and Sagaing Divisions)	TR	1,000,000; 103 deaths	US$ 9 million
	2014	India (Jammu, Kashmir)	HMR	200,000; 150 deaths	US$ 170 million
		Malaysia (Kelantan, Terengganu, Pahang)	HMR	404,000; 24 deaths	US$ 668 million
		Pakistan (Punjab, Gilgit Baltistan, Azad Jammu, Kashmir)	Flash flood	250,000; 367 deaths	US$ 1 million
	2013	Indonesia (Jakarta, West Java)	HMR	250,000; 47 deaths	US$ 500 million
		Malaysia (Johor, Kelantan, Terengganu)	HMR	37,480; 4 deaths	US$ 162 million
	2012	Philippines (Luzon, Metro Manila, Quezon)	TR	519,000; 95 deaths	US$ 14.31 million
		Malaysia (Pahang)	HMR	500	US$ 46 million
	2011	Northeast Japan	Tsunami	228,863; > 28,000 deaths	US$ 235 billion
		Pakistan (Sindh Province)	TR	530,000; 434 deaths	US$ 25 million
		Thailand (Provinces along Mekong and Chao Phraya River basins)	TS Nock-Ten	13,600,000; 815 deaths	US$ 45.7 billion
	2010	China (Zhejiang, Fujian, Hubei, Hunan, Guangdong, Guangxi, Gansu, Sichuan, Guizhou)	Flood	4241 deaths	US$ 51.4 billion
		Pakistan (Indus River, Khyber Pakhtunkhwa, Punjab, Sindh, Balochistan)	HMR	20,000,000; 1,985 deaths	US$ 43 billion

(continued)

Table 1 (continued)

Continent	Year	Country (State/City)	Flood event	Affected population	Financial loss
		Malaysia (Kedah, Perlis)	HMR	50,000; 28 deaths	US$ 8.48 million
	2009	India (West Bengal)	Cyclone Aila	2,000,000; 299 deaths	US$ 3.4 billion
		Saudi Arabia (Jeddah, Makkah)	HR	122 deaths	US$ 270 million
	2008	Myanmar (Irrawaddy Delta, Bogale, Labutta Township)	Cyclone Nargis	≥138,373 deaths	US$ 12.9 billion
		Saudi Arabia (Yemen)	TS	180 deaths	US$ 1.638 billion
		India (Western regions of Maharashtra state, Andhra Pradesh, Northern Bihar)	Bihar flood	3,000,000; 2404 deaths	US$ 230 million
	2007	Korea (Pyongyang)	TR	600 deaths	US$ 22.5 million
		Indonesia (Jakarta, Banten)	HR	500,000; 80 deaths	US$ 400 million
		Malaysia (Pahang, Johor)	HMR	172,000; 29 deaths	US$ 1.05 billion
		Pakistan (Baluchistan, Sindh)	Cyclone Yemyin	2,000,000; 730 deaths	US$ 2.1 billion
	2006	Korea (South Pyongan, North Hwanghae, South Hamgyong)	HR	151 deaths	US$ 20 million
		Malaysia (Selangor, Johor)	Flash flood	62,000;18 deaths	US$ 498.5 million
	2005	Pakistan (Kashmir, Pasni, Tehsil, Chaman)	Monsoon flood	12,000,000; > 1,600 deaths	US$ 3.2 million
		Malaysia (Kelantan, Terengganu, Kedah, Perlis)	HMR	20,000; 62 deaths	US$ 149 million
	2004	Malaysia (Peninsular Malaysia)	Tsunami	20,000; 83 deaths	US$ 205 million
	2003	Malaysia (Kedah)	HMR	45,000	US$ 3 million
	2001	Malaysia (Pahang)	HMR	18,000; 11 deaths	US$ 22 million
	2000	Malaysia (Kelantan, Terengganu)	HMR	8000; 12 deaths	US$ 11 million

(continued)

Table 1 (continued)

Continent	Year	Country (State/City)	Flood event	Affected population	Financial loss
		China (Chongqing)	TR	1,400,000; 701 deaths	US$ 13.7 billion
	1998	China (Yangtze River)	TS	240,000,000; 3656 deaths	US$ 30.7 billion
	1996	Central and Southern China	Typhoon Gloria	36,815; 3050 deaths	US$ 6.87 billion
		Malaysia (Sabah)	TS	241 deaths	US$ 300 million
	1991	China (Anhui, Jiangsu)	TR	2,630 deaths	US$ 13 billion
		Bangladesh (Chittagong, Kutubdia Upazila)	Super Cyclonic Storm BOB 01	≥138,866 deaths	US$ 1.7 billion
	1988	Malaysia (Kelantan)	HMR	36,800; 19 deaths	US$ 33 million
	1986	Malaysia (Kelantan, Terengganu)	HMR	500	US$ 18 million
	1975	China (Zhumadian, Henan Province)	Typhoon Nina	229,000 deaths	US$ 1.2 billion
	1971	Malaysia (Pahang)	HMR	153,000; 85 deaths	US$ 93.1 million
	1970	East Pakistan	Bhola Cyclone	3,600,000; ≥ 500,000 deaths	US$ 450 million
	1967	Malaysia (Kelantan, Terengganu, Perak)	HMR	678,000; 55 deaths	US$ 394 million
	1950	Pakistan (Punjab)	HR	11,239 deaths	US$ 800 million
	1939	North China	Tianjin flood	650,000; 200,000 deaths	US$ 94 million
	1935	China (Hubei, Hunan, Anhui, Jiangsu, Zhejiang)	Yangtze River flood	145,000 deaths	US$ 6.2 billion
	1931	China (Yellow River, Yangtze River, Huai River)	Central China flood	80,000,000; 3,700,000 deaths	US$ 28.5 million

[a]HMR = Heavy monsoon rainfall; HR = Heavy rainfall; SS = Storm surge; TR = Torrential rain; TS = Tropical storm.

3 Flood Mitigation Measures

Floods are the unpredictable and prevailing disaster situations, where the existing protective action plans and measures relevant to the flood risk management system are found to be insufficient in controlling the incidences in different regions of the world. Therefore, in an effort to minimize the future flooding and its impacts, some normative improvement actions, including structural flood-mitigation measures and non-structural emergency responses, or with the progressive collaborative-participation between government and stakeholders (public communities and private agencies within the disaster-affected areas) has received substantial attentions.

Structural flood-alleviation measures can be defined as different types of "hard" infrastructure, including dyke, levee, embarkment, detention basin, drainage channel, floodgate/ sluice gate, diversion channel, pumping station, dam/ reservoir and flood-mitigation ponds, which are permanently constructed singly or in combination, with the primary aims to reduce the potential risk or control the surplus water runoff in an event of a flood. Meanwhile, non-structural flood control measures are "soft" preventive techniques, particularly flood risk and impact assessment, flood forecasting and warning system, flood-risk awareness and education program, flood insurance and resilience policy, land-use planning and floodplain zoning, and post-disaster recovery. The mitigation strategies for the flood disaster management, and the social and environmental measures of the non-structural flood control are demonstrated in Tables 2 and 3, respectively.

Among the general approaches, structural measures are the important supplementary tools as compared to the non-structural measures in the context of adaptation to the changes of climate and land use. From the comprehensive literature review, the structural mitigation techniques adopted for every single part of the country are site specific, which are largely dependent on the climate change, sea level rise, land use patterns and the function of the hydraulic structure. The main structural measures undertaken against flooding are:

Table 2 Strategies for flood disaster management

Strategy	Option
(a) Flood reduction	Dam; Dyke; Flood embankment; Flow diversion channel; Flow retardation basin; Channel improvement; Wetland; Wet and dry ponds system
(b) Susceptibility reduction to damages	Floodplain regulation; Flood-proofing; Flood-control facilities; Flood-resistant building codes; Policies
(c) Impacts mitigating	Disaster preparedness; Forecasting, warning and response system; Flood awareness and education programme; Flood insurance and resilience policy; Post-disaster recovery
(d) Resource preservation of floodplains	Flood zoning; Floodplain zoning and regulation; Land-use planning

Table 3 The social and environmental measures of the non-structural flood controls

Flood reduction strategy	Non-structural measure	
	Environmental measure	Social measure
Dams	Increase natural water retention and water storage in watersheds by extending floodplains, and development of wetlands and polders	Flood mitigation systems, including forecasting, warning, evacuation and post-flood recovery
Dyke and levee	Enhance infiltration and retardation of water by reducing impermeable areas	Land-use planning
Water storage reservoirs for flood control	Agriculture practices reducing runoff	Local and transboundary emergency committees
Off-stream polders/ flood retardation ponds	Zoning to delineate floodplain, with low-value infrastructure	Household mitigation and preparedness actions
Dykes	Appropriate planning, management and construction techniques in flood-prone areas	Capacity-building for knowledge, awareness, and understanding improvement for flood disaster risk management
Flood protection embankments and floodwalls		Risk-spreading through flood policies, insurances and plans

(a) Water retention mechanisms, such as dam and retention of storing floodwater are suggested in the upstream area
(b) The repair of hydraulic structures to better control of floodwater, and improvement of emergency retention area are suggested in the midstream area
(c) The enlargement of drainage capacity through canal dredging, and installation of more pumps as well as dykes repair to facilitate the water flow are suggested in the downstream area

Structural measures continue to dominate in the flood control management; however, improvement in soil–water storage capacity and land-use management are the key solution for flood risks reduction. According to the recent study carried out by Kourtis et al. [27], the environmental implications of flood-control systems can be minimized by harmonizing the future designs of resilient flood defense measures with the surrounding environment and ecosystem. The typical example is the setup of nature protection, including marshes or wetlands as a mean of minimizing the damages and erosions from storm surge flooding. This wetland design can be established through revegetation of upper catchment areas, polders removal, floodplains and wetlands restoration as part of post-disaster reconstruction, to improve the natural stability. This strategy could provide societal and environmental benefits to the public for the better floodplain management, dam rehabilitation and coastal resilience via transition subsidies, development of alternatives livelihoods, improvement of water quality and the restoration of fish stocks. Based on the modern engineering infrastructure systems, wetlands have the greatest ability to stabilize the streambanks by providing a zone of “flat” topography, and wetlands adjacent to riverine systems demonstrate a wide array of values that include retention capacity, nutrient and pollutant uptake, flood attenuation, recreation and preservation of vegetation and wildlife.

In the long-run, these flood preventive measures are not as effective as expected in the real life, as the number of flood-affected areas in different part of the world has remained high during the last five decades. Therefore, non-structural measures, including the use of legislation for the enforcement of planning criteria, restriction of development and construction on natural floodplains, land-use planning and zoning, population resettlement, flood forecasting technique, flood early warning system, flood proofing and flood insurance should be adopted when the engineering measures are not applicable or viable. Additionally, structural improvement on the organization framework, coastal zone planning, and public awareness and education programs have also been implemented as non-structural flood risk management measures. Most of these non-structural management are relatively simple, cost-effective, environmental-friendly, feasible and amendable, but problems do exist, partially related to the insufficient legal and technical support, and limited case studies driven by the impacts of climate change, population growth, land use/ cover, political and socio-economic development.

Both of the structural and non-structural strategies, however, must involve the public/ victims from all stages, and the residents of the flood hazard areas must be familiar with those measures, in minimizing the loss and damages. Within this context, the integrated strategies, ranging from regulations on land use, infiltration facilities, non-structural emergency response to structural measures, with the involvement of different stakeholders, notably from central and local governments, local communities and private agencies, specifically on water resources management, agriculture, housing, forestry and urban planning, is the key to build a robust system. Moreover, this effective integrated paradigm should consist of these three key research approaches: (1) Establishment on the structural flood protection system, (2) Water storage capacity improvement, and (3) Implementation of social mitigation strategy (land-use, forecast and warning systems, community emergency and household mitigation actions), to generate flood-resilient communities and reduce the compounding risk in the near future.

4 Conclusion

Knowledge of the past is a key for the understanding of the present and future, specifically for the hydrological and climatological events. To date, these flooding systems are set to be continuously increased throughout the world due to the flood-relevant aspects of global changes: climate change, land use and land cover, urbanization, morphology and river channel system. These critical risk receptors have affected the flood risk at different levels, in term of retention capacity and the potential damages in floodplains adjacent the river, and vulnerability of economic loss in the flood-endangered areas. Yet, until today, the information related to the extreme floods' course, expansion and intensity, are limited to the national level. Therefore, the reconstruction of documentary descriptions of historical floods, in term of the causes and aftermath effects of different extreme water-related weather events in different world regions, is gaining large interest in this present article. The general estimation of flood risks, the design and operation of hydraulic and protective infrastructures, and emergency management planning are presented. Conclusively, an integrated management and planning of flood risk must be tailored to the need of local health jurisdictions to a great extent on minimizing the total damage driven by the flood events, resulting in an optimization and adaptation of multidisciplinary and sustainable flood protection technologies against future potentially disastrous flood tragedy.

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Road Accident Hazard Prevention by Applying the Haddon Matrix

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Abstract Road accidents are causing a large number of losses. Road accidents become a hazard for low to middle-income countries; as these countries share a major amount of crashes on a global scale. With the increase in population and motorized vehicles, the accident scenarios become more complex for countries like India. Injuries and fatalities caused due to a crash are affecting the mental, physical as well as financial status of the victim's family. Collectively, higher numbers of fatalities cause a much higher influence on the human development of the country. Therefore, a strategic approach is a must to prevent road accidents and related causalities. The sole objective of the present study is to determine the crash influencing parameters within Gujarat. The majority of study data is harvested from the annual road accident report provided by the Ministry of Road Transport and Highways. The collected data is categorized into different sets of sub-parameters. Particular categorization helps to understand the overall impact of sub-parameter. The related sub-parameters are put under the major influencing factors stated as human factors, vehicular factors, road and environmental factors. These major factors are integrated during the study by applying the Haddon matrix. The Haddon matrix highlighted the major influencing determinants for Gujarat. The analysis provides the most affecting factors at pre-crash, during the crash, and post-crash scenario with preventive strategies at every stage.

Keywords Road accident hazard · Crash influencing factors · Haddon matrix

1 Introduction

With the increase in traffic and population within the South Asian countries, road accidents increase simultaneously. Road accident disease burden is expected to become third within the year 2020 with 90% of road accident deaths shared by only lower to middle-income countries [1]. Indian road accident death rates highlight the hazardous

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scenario of the situation. The study of the current situation predicted that the road accident deaths within India will cross the mark of 250,000 by 2025 [2]. Because of this alarming condition, the families of accident victims are facing financial, social as well as mental health issues. The government of India is taking many steps to minimize accident-causing situations, but due to the simultaneous increase of population as well as the registered vehicles within the country; it becomes difficult to handle the situation. Many researchers focus their efforts to investigate the factors which influence the fatalities and injuries caused by road accidents within different demographic conditions. Related research papers listed accident influencing parameters based on the detailed situational study, from which most of the factors are sub-grouped as Human factors, Vehicular factors, Road and Environmental factors [3–5]. Integrated analysis of these factors becomes essential to reduce the risk of road accident hazards in any condition. The Haddon matrix-based evaluation was conducted for presented research to analyze the accident-causing parameters.

2 Methodology

Firstly, the main data source center was selected for accurate road crash data. The accuracy of data is a must to develop a more relevant analysis of the current situation. An annual report on the road accident trends within the country is published by The officials of the Ministry of Road Transport and Highways, India. The report contains detailed information about the road crashes that happed during any particular year. As the reports are very well-generated with detailed information, the raw data for this study is collected from the annual report of 2019 [6]. The critical analysis resulted in the highlighted issues which influence the road crash most within Gujarat. The analyzed data helped to form the Haddon matrix with the demonstrated strategies to reduce road accident hazards. The strategies involved mainly depend on the nature of major road crashes. The Haddon matrix formed at the end of the analysis allows linking the crash influencing factors with the accident occurring phases in the most optimized manner. Figure 1 represents the steps involved in the analytical process with demonstrated strategies.

3 Analysis of Road Accident Hazard Influencing Factors

3.1 Human Factors

The total number of accidents and related fatalities are analyzed based on human factors like gender, age, use of safety devices, type of traffic violation by the drivers, collision conditions, and the driving license status. The listed parameters are based on human behavior and related characteristics. Male commuters are affected most

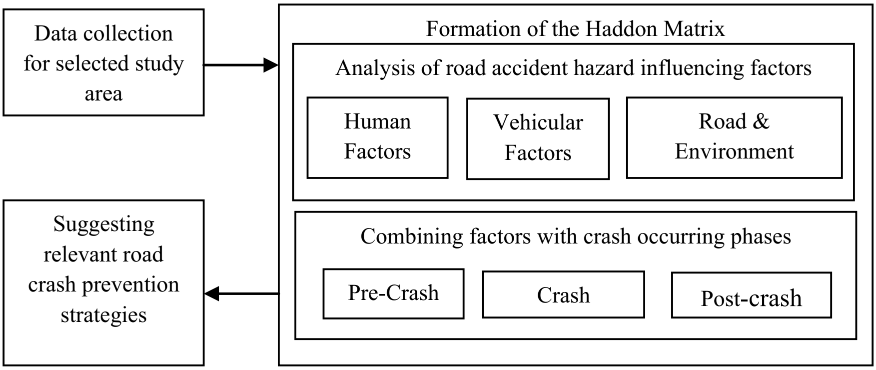

Fig. 1 Methodology to provide accident prevention strategies using the Haddon matrix

by road crashes as compared to female commuters. The age group of 25–35 years of male drivers shared the majority of crash deaths [24.75%]. The overspending of vehicles caused a major amount of road accidents [84.85%] as well as crash deaths. The analysis stated that vehicle collisions caused most of the fatalities for Gujarat. The rear-end collision caused most of the deaths [24.33%] and only a small amount of drivers faced fatality by hitting on any fixed objects [2.79%]. The use of safety devices may reduce injury severity while going through a road crash. But, analysis noticed only a satisfactory number for using safety devices while driving. Two-wheeler drivers were more prone to fatalities as compared to passengers, due to lack of helmet usage. On other hand, the injury rates were noted more for four-wheeler drivers and passengers as compared to death rates, due to lack of seat belt usage (Table 1).

3.2 *Vehicular Factors*

Vehicle plays a great role while ensuring the safety of the driver and passengers. Generally, new vehicles are less prone to accidents as compared to vehicles in use. But still, driver's skills and other factors like maintenance of vehicles play a crucial for ensuring safety. The non-motorized vehicles [18.87%] of Gujarat state were noted as less affected by road crashes as compared to the motorized vehicles [81.12%]. Two-wheeler vehicles faced the most difficulties during 2019 and faced the highest fatality share [39.67%] for Gujarat, followed by car, taxi, van, other LMV [19.89%], and pedestrians. The slide shift in the center of mass of the overloaded vehicles is often resulting in the overturning of vehicles at road turns and curved sections. The overturning of overloaded vehicles is causing fatalities as well as heavy injuries to the vehicles passing by the incident site. Surprisingly, the death caused by the overloaded vehicles [7.23%] was noted very much less than the normally loaded vehicles [51.96%] (Table 2).

Table 1 Distribution of human factors—Gujarat 2019

Age and gender

		Deaths	% of deaths
less than 18 years	Male	278	3.76
	Female	84	1.14
18–25 years	Male	1277	17.28
	Female	196	2.65
25–35 years	Male	1829	24.75
	Female	297	4.02
35–45 years	Male	1575	21.31
	Female	271	3.67
45–60 years	Male	971	13.14
	Female	179	2.42
60 and above	Male	238	3.22
	Female	101	1.37
Age unknown	Male	77	1.04
	Female	17	0.23
Total		7390	100

Traffic violation

	Total accidents	Deaths	% accident share	% of deaths
Drunken driving	47	17	0.28	0.23
Over speeding	14,464	6343	84.85	85.83
Driving on the wrong side	607	225	3.56	3.04
Jumping red light	8	4	0.05	0.05
Use of mobile phones	122	40	0.72	0.54
Other	1798	761	10.55	10.30
Total	17,046	7390	100	100

Collision characteristics

	Total accidents	Deaths	% Accident share	% of deaths
Hit and run	2893	1529	16.97	20.69
Collision with parked vehicles	748	310	4.39	4.19
Hitting from the back	4760	1798	27.92	24.33
Hitting from the sides	3,243	1,203	19.02	16.28
Collision with the fixed objects	358	206	2.10	2.79
Overturning of vehicle	1012	549	5.94	7.43
Head on collision	1761	754	10.33	10.20
Running out the road	1340	550	7.86	7.44
Other	931	491	5.46	6.64

(continued)

Table 1 (continued)

Collision characteristics

	Total accidents	Deaths	% Accident share	% of deaths
Total	17,046	7390	100	100

Helmet and car seat belt usage

		No helmet	No seat belt
Driver	Deaths	1365	635
	Injured	2038	1172
Passengers	Deaths	648	812
	Injured	1537	1945

Driving license status

	Total accidents	% Accidents share
Valid permanent license	11,936	70.02
Learner's license	1070	6.28
Without license	1245	7.30
Unknown	2795	16.40
Total	17,046	100

3.3 Road and Environment Factors

Road geometry conditions modify the driver's general behaviors. The senses of drivers get tricked by the sudden change in road features and conditions which pressurized drivers to apply the sudden breaking. Adverse environmental conditions like hail storms, excessive fog, heavy rain pressurized vehicles to perform at their optimized efficiency; which may cause mechanical failures. Open area contributed to most deaths [68.29%] as it allows drivers to accelerate the vehicles, most. Further analysis of road features highlighted that the strait roads caused the most fatality [79.02%] followed by the curved roads [12.47%]. The staggered road junctions influenced most accidents [28.84%] as well as deaths [32.56%] for Gujarat in 2019. Most accidents were caused in January [10.06%] but most fatalities were noted down during May [10.17%]. The pick-hour traffic of Gujarat state caused most of the accidents as well as deaths. Specific evening rush hours caused nearly the fifth half [20.95%] of road accidents (Table 3).

Table 2 Distribution of vehicular factors—Gujarat 2019

	Total accidents	Deaths	% Accident share	% of deaths
Type of vehicles				
Pedestrian	2745	1291	16.82	18.59
Bicycles	238	84	1.46	1.21
Other non-motorized vehicles	96	41	0.59	0.59
Two wheelers	6412	2755	39.30	39.67
Auto rickshaws	1088	375	6.67	5.40
Cars, taxis, vans and LMV	3349	1381	20.53	19.89
Trucks	1877	817	11.50	11.77
Buses	511	200	3.13	2.88
Total	16,316	6944	100.00	100.00
Vehicle loading conditions				
Normally loaded	9274	3840	54.41	51.96
Overloaded	1033	534	6.06	7.23
Others	6,739	3016	39.53	40.81
Total	17,046	7390	100.00	100.00
The age of vehicles				
Less than 5 years	4994	2060	29.30	27.88
5–10 years	4469	1797	26.22	24.32
10–15 years	1933	877	11.34	11.87
> 15 years	2020	930	11.85	12.58
Age unknown	3630	1726	21.30	23.36
Total	17,046	7390	100.00	100.00

4 The Crash Phases Analysis

4.1 Pre-crash Phase

Young male drivers having low to middle socio-economical backgrounds are often involved in road crashes. Non-motorized vehicle faces very few crashes instead of not having safe infrastructural conditions, at the pre-crash phase. Motorized vehicle causes more accidents as well as fatalities because of high speed and differed road conditions. Most accidents are caused within the rush hours and lunch hours due to heavy urban traffic.

Table 3 Distribution of road and environmental factors—Gujarat 2019

Road factors				
Type of functional area				
	Total accidents	Deaths	% Accident share	% of deaths
Residential area	3703	1330	21.72	18.00
Institutional area	1088	384	6.38	5.20
Market area	1,976	629	11.59	8.51
Open area	10,279	5047	60.30	68.29
Total	17,046	7390	100.00	100.00
Type of road features				
	Total accidents	Deaths	% Accident share	% of deaths
Strait road	13,718	5838	80.48	79.00
Curved road	2092	921	12.27	12.46
Bridges	546	270	3.20	3.65
Culvert	273	135	1.60	1.83
Pot holes	5	5	0.03	0.07
Steep grade	204	117	1.20	1.58
Ongoing road works	206	102	1.21	1.38
Other	2	2	0.01	0.03
Total	17,046	7390	100.00	100.00
Type of road junctions				
	Total accidents	Deaths	% Accident share	% of deaths
T-junction	1451	635	26.41	26.61
Y-junction	529	237	9.63	9.93
Four arm junction	1242	491	22.60	20.58
Staggered junction	1585	777	28.84	32.56
Round about junction	688	246	12.52	10.31
Total	5495	2386	100.00	100.00
Type of road controls				
	Total accidents	Deaths	% Accident share	% of deaths
Traffic light signal	208	46	3.79	1.93
Police controlled	402	141	7.32	5.91
Stop signing	144	54	2.62	2.26
Blink inker	82	22	1.49	0.92
Uncontrolled	4659	2123	84.79	88.98
Total	5495	2386	100.00	100.00

(continued)

Table 3 (continued)

Environmental factors

Sectional features

	Total accidents	Deaths	% Accident share	% of deaths
Sunny/clear	15,014	6462	88.08	87.44
Rainy	1364	656	8.00	8.88
Foggy and misty	668	272	3.92	3.68
Hail/sleet	0	0	0.00	0.00
Total	17,046	7390	100.00	100.00

Monthly distribution

	Total accidents	Deaths	% Accident share	% of deaths
January	1715	658	10.06	9.78
February	1632	642	9.57	9.55
March	1580	622	9.27	9.25
April	1448	595	8.49	8.85
May	1624	684	9.53	10.17
June	1404	563	8.24	8.37
July	1248	476	7.32	7.08
August	1182	423	6.93	6.29
September	1085	422	6.37	6.27
October	1356	538	7.95	8.00
November	1285	488	7.54	7.26
December	1487	615	8.72	9.14
Total	17,046	6726	100.00	100.00

Timely distribution

	Total accidents	% Accident share
06–900 h	1791	10.52
09–1200 h	2523	14.82
12–1500 h	2564	15.06
15–1800 h	2901	17.04
18–2100 h	3566	20.95
21–2400 h	1916	11.25
00–300 h	944	5.55
03–600 h	819	4.81
Total	17,024	100.00

4.2 Crash Phase

Most non-motorized drivers, pedestrians, and two-wheeler drivers suffer severe injuries or fatalities during the crash phase. Open area and residential areas influence most fatalities during this phase. Open area allows drivers to accelerate the vehicles at maximum speed which may cause an error in the driver's perspective or mechanical failure of the vehicle.

4.3 Post-crash Phase

The quick first aid responses to the victims are a must to save a victim's life. The absence of trauma centers near an accident blackspot increases the chances of a victim's death. Often the ambulance and other quick response vehicles are delayed due to heavy city traffic conditions. Delay of emergency vehicles is often neglected while forming policies for road safety. Additionally, citizens have very little knowledge of road safety practices which causes uncertain situations around crash spots during the post-crash phase.

5 The Haddon Matrix Analysis with Crash Prevention Strategies

The effective use of the Haddon matrix as the accident analysis tool has been used since 1970. The matrix provided with the subdivision of crash phases as Pre-crash, Crash, and Post-crash; facilitating factors involved within each of the stages [7, 8]. But, still, the evaluation of crash severity often does not rely on the Haddon matrix. The following analysis is covering the evaluation of accident data based on the crash influencing factors suggested by William Haddon [7].

A particular study provides a direct insight into the factor influencing the road hazards within every crash phase, provided with the prevention strategies. Table 4 provides the Haddon matrix for the state of Gujarat with systemic approaches to reduce road accident hazards. The most influenced determinants which influence the road crashes most are only presented within the matrix.

The Haddon matrix indicates the most affecting crash determinants for the state of Gujarat. A well-planned strategic approach for policymaking with technological modification is a must for the state to reduce accident hazards. The policymakers of the state must imply an educational program related to road safety practices. The program must be included as part of the school curriculum and for technical studies too. The law enforcing the cancellation of driving license for rash driving develop safe driving practices within the drivers. Added use of public transportation will reduce the urban traffic of major cities of the state with the overall reduction

Table 4 The Haddon matrix of road crash hazard determinants with crash reduction and prevention strategies

	Human factors	Vehicular factors	Road factors	Environmental factors
Pre-crash Phase	– Victim's age – Victim's gender – No registered license	– Non-motorized vehicles – Vehicle's age	– Open area – Uncontrolled traffic points – Staggered sections	– Visibility conditions clear sky/sunny day – Month of May
Crash Phase	– Hitting from back – Use of Helmet and Seat belt	– Vehicle's crashworthiness	– Strait roads – City area	– Morning rush hours and Lunch hours
Post-crash Phase	– Injury severity of driver and passenger	– Vehicle's crash condition	– Proximity to trauma centers – Delay timing in the arrival of emergency vehicles	– Weather conditions like heavy rain, hail, storms
Crash reduction and prevention strategies	– Implementation of road safety awareness programs at every desired educational level – Strict legal actions against the guilty driver with the provision to suspend the license and impoundment of the vehicle [9]	– Strengthening the policies related to the use of Public transportation over private vehicles – Maximizing safety standards of vehicles – Introduction of the automatic emergency brake system [10]	– Development of road network connecting trauma facilities [8] – Designing the roundabouts to reduce the road crash [11] – Application of skid resistance coating for the wet condition [12] – Lane separation for motorized and non-motorized vehicles [13]	– Critical analysis of accident hotspots under adverse weather conditions – Strengthening the traffic controls during pick hours

in the use of private vehicles. The particular strategy has the potential to reduce traffic congestion, which directly reduces the probability of a road crash occurring. The vehicles must be enabled with the emergency braking systems to reduce the reaction time of drivers with the reduction of braking distance as well [10]. Proper road network planning becomes more essential to handle heavy urban traffic. To handle heterogeneous traffic, lane separation rises the safety advantages for non-motorized vehicles [13]. The introduction of skid resistive coating on the pavements helps motorized vehicles to grip vehicles well in adverse climate conditions [12].

6 Conclusion

The uncontrolled growth in private vehicles with a rising population rings the bells for India to reduce road crash hazards. A well-integrated multidisciplinary collaborated works having the potential to come out with newly developed crash safety practices become more important. The simple yet effective approach of the Haddon matrix analysis provides a clear idea about influencing crash determinants of the study area. The Haddon matrix analysis for the state of Gujarat highlights the area to be considered most while developing road safety policies of the state. The analysis states that the majority of road crashes are directly or indirectly influenced by human factors, so further analysis becomes essential. The present analysis supports the importance of road safety awareness education among citizens. Intrinsically, existing road safety practices according to crash phases have to reconsider for further improvement with interdisciplinary crash hazard reduction strategies.

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No Fine Concrete Pavement—A Sustainable Solution for Flood Disaster Mitigation

R. Jeya Prakash, B. Soundara, and Christian Johnson

Abstract No Fine concrete (NFC) pavement is an ecologically sensible and sustainable substitute for conventional impervious concrete or asphalt pavement structures. Due to the omission of fine aggregates, the concrete can exhibit a porous structure called Pervious or No Fine concrete (NFC). The key design of the NFC system is to introduce acceptable void content so that excess runoff water does freely infiltrate being a self-resilient infrastructure. This can be achieved by controlling or totally removing the proportion of fine aggregates from the mixture design. In this current research, the mechanical properties including compressive strength, split tensile strength, and the hydraulic conductivity (i.e., permeability) of Fibre Reinforced No Fine Concrete (FRNFC) were discussed. Fibres with an effective length of 36 mm, and dosage rates of 0.15, 0.30 and 0.45% are taken for this present investigation. The volume fraction of the water to binder ratio is kept constant at 0.28. The addition of fibre doesn't have substantial effects on strength parameters and diminish the permeability of NFC to an insignificant degree. However, this polypropylene fibre reinforcement is done, to ensure the durability parameters such as abrasion and freeze–thaw resistance which are the perennial concern for implementation.

Keywords No fine concrete · Fibre reinforcement · Permeability · Porosity · Flood mitigation · Sustainable concrete

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1 Introduction

1.1 Problem Statement

No Fines Concrete (NFC) is an extremely sustainable, environmentally friendly material that creates an open cell structure due to the absence of fine aggregates which allows permeability in it. The storm water runoff loss estimated in the rural areas and villages was about 14–19% with above 80% of infiltration rates. Besides, the same measured in urban areas reach up to 94% of runoff losses allowing only 6% of volume for infiltration [1]. This is an effect of increased volume of impervious layer over the surface of the earth in urban areas, causing high environmental impacts [2]. This is also considered to be a source of pollution, in which various pollutants over the surface are washed and mixed into the water bodies at the time of runoff [3]. To reduce this adverse effect of storm water runoff, there should be a proper drainage facility and rainwater harvesting at the source level should be encouraged among the residents. The government has taken many steps to spread awareness about rainwater harvesting and its benefits, but still, this method is not suitable for cities like Chennai with densely populated. This can also be avoided by installing pervious or NFC pavements, besides these environmental benefits some of the drawbacks like less strength, durability, and high chance of clogging restrict its application in real-time [4].

1.2 Research Significance

The Literature study inferred that the durability parameters such as the resistance offered against abrasion and freeze–thaw durability of NFC have been enhanced significantly due to the addition of fibre, but still, there is no technical guidance about the dosage and fibre length [5, 6]. Further, literature shows a variety of compressive strength values ranging from 3.5 to 25 N/mm^2 [7]. If the strength is of primary concern, NFC can be produced by several practices such as increasing the compaction energy, confinement to the sample, etc., with low permeability [8]. The main objective of this study is to produce an optimal mixture proportion for FRNFC with higher performance in strength parameters without compromising their permeability value and to investigate the effects of aggregate size, aggregate to binder ratio, and the fibre proportion on their mechanical and hydraulic properties.

2 Methodology

Methodology of this research includes the selection of aggregates as in Fig. 1 and the selection of fibre as in Fig. 2.

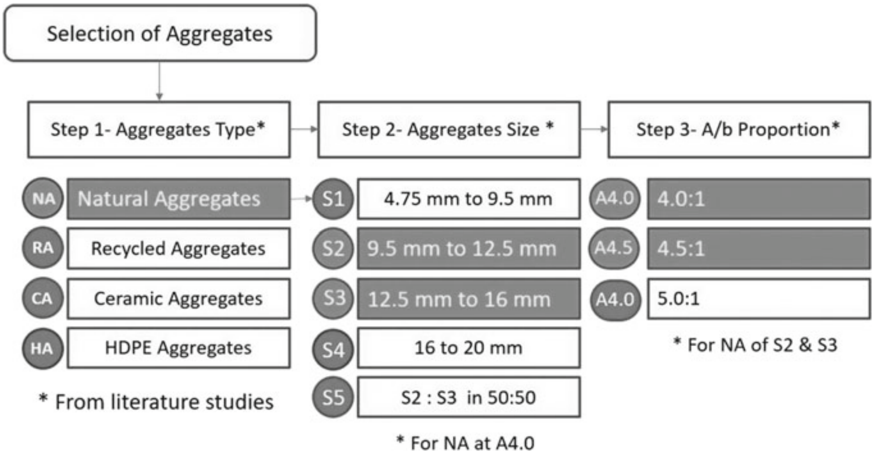


Fig. 1 Selection of aggregates

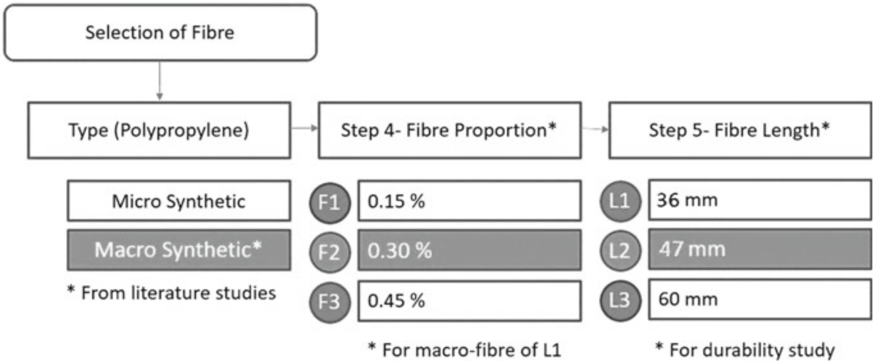


Fig. 2 Selection of fibre

Among the various type of aggregates and fibre: natural aggregates and macro synthetic fibres are taken for this study based on the literature study conducted [9, 10]. This paper presents the test values of structural and hydraulic properties of fibre reinforced no fine concrete. The additional characteristics such as effects of fibre length on the resistance against abrasion and freeze and thaw, the pore size distribution of FRNFC can be studied using imaging technology [11].

3 Material Properties and Testing

This section presents the test results of the materials used in this study. Among the various grades of cement available in the market, Ordinary Portland cement of 53

Table 1 Properties of OPC 53 grade based on test results

Specific gravity	Fineness (%)	Standard consistency (%)	Initial setting time (min)	Final setting time (min)	Bulk density (kg/m^3)
3.15	8	30	33	570	1411

grade—Zuari Cement (Commercial name) opts for this study [12]. The various test results of cement are given in Table 1.

The aggregates are categorized into S1, S2, S3 and S4 [13, 14] (S1—passing through 9.5 mm sieve and retained on 4.75 mm sieve, S2—passing through 12.5 mm sieve and retain on 9.5 mm sieve, S3—passing through 16 mm sieve and retained on 12.5 mm sieve and S4—passing through 20 mm sieve and retained on 16 mm sieve) and their test results are given in Table 2. The aggregates of the same size range produce high values of permeability. Whereas aggregates of the different sizes are used in the same mixture, the lower size aggregate fill the pore space between the large aggregate resulting in high strength but comparatively very less permeability. The aggregate to binder ratios of 4.0:1, 4.5:1, and 5.0:1 are taken and their effects on mechanical and hydraulic properties of NFC have been examined. For NFC, the optimum water cement ratio can be taken between 0.26 and 0.30 [2] and in this study, it is kept constant as 0.28.

The macro synthetic polypropylene fibre of 0.15, 0.30, and 0.45% in the volume of cement is added to NFC to study their effects and their properties are listed in Table 3.

Table 2 Aggregate properties based on test results

Aggregate size	Specific gravity	Water absorption (%)	Bulk density (kg/m^3)
S1—4.75–9.5 mm	2.86	0.98	1595
S2—9.5–12.5 mm	2.68	1	1513
S3—12.5–16 mm	2.94	1	1542
S4—16–20 mm	2.91	1.15	1660

Table 3 Properties of macro synthetic polypropylene fibre

Specific gravity	Effective length (mm)	Aspect ratio	Young's modulus (kN/mm^2)	Tensile strength (kN/mm^2)	Bulk density (kg/m^3)
0.91	36	46	4.0	0.55	910

3.1 Casting and Curing of Test Samples

The concrete was batched and mixed using a rotating-drum mixer for appropriate mixing, and the fibres were added at last by sprinkling to ensure uniform mixing [15]. Then the prepared mixture was placed in cube molds of 150 mm × 150 mm × 150 mm size and cylindrical molds of 150 mm diameter and 300 mm height for the estimation of compressive and split tensile strength respectively. For permeability check using constant head permeameter, the samples are prepared by placing the mixtures in PVC cylindrical molds of 100 mm diameter and 200 mm height. The casted specimens are demolded after 24 h and subjected to curing for 28 days. All the test for strength parameters was conducted according to IS:516–1959.

3.2 Test Procedures

Flowtable Test. The Flowtable test is conducted to calculate the consistency in flow percentage and can be used to determine the workability of a freshly prepared concrete mix. It consists of a circular table, fixed with a rotating wheel and a mold is firmly placed over the center of table in which the concrete is filled in two layers. After leveling the surface, the mold is removed steadily upward without disturbing the sample. The flow table is raised and dropped from a height of 12.5 mm, 15 times in about 15 s. The average diameter of spread in six symmetrical directions in the table is used to measure the flow.

$$\text{Flow \%} = \frac{\text{Spread diameter(in cm)} - 25}{25} \times 100$$

Compressive Strength. Compressive strength is generally calculated for concrete cube specimen to evaluate their quality and performance. The values tabulated in Tables 4, 5, and 8 were reported based on the average values obtained from the compressive strength test of three cube specimens on 7 and 28 days of curing.

Split Tensile Strength. Cylindrical specimens of standard dimensions were tested against a split tensile strength test, after curing for 28 days. All the values tabulated were based on the average values obtained from three test samples. Since the application of this type of concrete is restricted to pavements applications, testing of beams (Flexural strength test) is neglected.

Hydraulic Conductivity. Hydraulic conductivity or Permeability is a property of any porous material which permits the flow of fluids through their interconnecting voids [16] and is measured using a constant head permeameter for cylindrical samples with 100 mm diameter and 200 mm height. The samples are subjected to vacuum wash, to get more accurate results.

Table 4 Trial mix design (for varying aggregate size, w/b ratio of 0.3 and A/b ratio of 4.0:1)

Mix ID	Mix name	Cement (kg/m^3)	Aggregate (kg/m^3)	Water (l/m^3)	Compressive Strength (N/mm^2) 7 days	28 days	Split Tensile strength (N/mm^2)	Flexural strength (N/mm^2)	Permeability (cm/s)
M1	A4.0S1	267	1208	53.0	11.12	15.86	1.53	2.87	0.89
M2	A4.0S2	267	1146	53.0	8.57	12.32	1.47	2.42	1.26
M3	A4.0S3	267	1168	53.0	5.36	8.65	1.32	2.34	1.40
M4	A4.0S4	267	1258	53.0	4.67	6.07	1.15	1.86	1.53
M5	A4.0S5	267	1157	53.0	10.28	14.87	1.40	2.15	0.97

Table 5 Trial mix design (for varying A/b ratio, aggregate size—S2 and S3, w/b ratio of 0.3)

Mix ID	Mix name	Cement (kg/m^3)	Aggregate (kg/m^3)	Water (l/m^3)	flow %	Compressive strength (N/mm^2)		Split Tensile strength (N/mm^2)	Flexural strength (N/mm^2)	Permeability (cm/s)
						7 days	28 days			
M2	A4.0S2	267	1146	53.0	110	8.57	12.32	1.47	2.42	1.26
M3	A4.0S3	267	1168	53.0	104	5.36	8.65	1.32	2.34	1.40
M6	A4.5S2	244	1178	48.4	98	10.45	14.50	2.06	2.12	1.37
M7	A4.5S3	244	1201	48.4	90	9.96	13.09	1.97	2.03	1.58
M8	A5.0S2	225	1205	44.6	84	7.81	8.49	1.34	1.98	1.06
M9	A5.0S3	225	1228	44.6	52	4.94	7.14	1.23	1.56	1.14

4 Mix Design

The effects of aggregate size and proportion on No Fine Concrete (NFC) are studied, based on the test results the best performing mixes [17] were taken to investigate the effects of fibre reinforcement.

The compressive, split tensile strength, and permeability values are based on the average value of three samples [18–20]. It is observed that the mixture containing S1, S2, and S3 produces a high value of compressive strength compared to the mixture containing S4. This is because the thin film of cement pastes forms better bonding with smaller-sized aggregates. While considering the coefficient of permeability, the mixture containing S3 and S2 performs well compared to that of the mixture containing S1.

This may be caused because of the decrease in pore size with a decrease in the nominal size of the aggregates. A new mixture ID, M5 is prepared with the aggregates of sizes S2 and S3 in equal proportion (i.e., 50:50). In which about 40% of pores in S3 type aggregates are filled with S2, and thereby increasing the strength parameters and decreasing the overall porosity. From the results obtained, further testing is restricted to the aggregate size of S2 and S3. Thus, the effects of aggregate proportion on NFC are studied for S2 and S3 with an aggregate to binder ratio of 4.0:1 (A4.0), 4.5:1 (A4.5), 5.0:1 (A5.0). Change in aggregate to binder ratio affects the workability of the mixture to a significant extent [21]. The increase in aggregate proportion decreases the flow value index and has produced a significant increase in strength parameters up to an extent but holds comparatively low permeability.

The further increase in aggregate proportion (i.e., >5.0:1) reduces the strength parameters, which may be due to the insufficient binder paste around the aggregates. And it is also very hard to work with mixtures containing high aggregate contents. Similarly, for mixtures with less aggregate content (i.e., <4.0:1) the flow value index increases, and segregation takes place. From the above trial mixes in Table 5, it is highly recommended to choose M2, M3, M6, and M7 for finding the effects of varying fibre proportions (Table 6).

Fibre reinforcement may reduce some specific performance, to stabilize and enhance the desired mechanical characteristics of Fibre Reinforced No Fine Concrete (FRNFC) such as bond strength between aggregates and cement paste, workability of the mixtures, additional admixtures such as viscosity modifying agent, VMA (Eucoplacant-721) and water-reducing agent, WRA (Auramix-400) confirming to the requirement of IS: 9103–1979, are added in optimal dosage as given in Table 7.

Along with these two admixtures, 12 mixture designs were prepared for three dosages of varying fibre proportions 0.15% (F1), 0.30% (F2) and 0.45% (F3) as shown in Table 8.

Table 6 Workability of mixture with respect to flow percentage

Flow percentage	0–20%	20–60%	60–100%	100–120%	120–150%
Consistency	Dry	Stiff	Plastic	Wet	Sloppy

Table 7 Admixtures composition

Admixture	VMA	WRA
Dosage (%)	0.30	0.25

5 Result and Discussion

This section presents the test results for FRNFC specimens containing various fibre proportions in Table 8. It includes the effects of change in aggregate size and proportion, the effects of change in fibre proportion in their mechanical and hydraulic characters of various mixture proportions. The volume fraction of water to binder ratio is kept constant at 0.28 for all mixtures.

5.1 Effect of Change in Aggregate Size

The aggregate size determines the pore structure of concrete, say for smaller aggregates the pores present were also small, and for larger aggregates, the pore structure was comparably large. The above conditions changed vice-versa considering the strength parameters. The line chart in Fig. 3, stretches the effects of aggregates size on permeability and strength parameters. From this, we can evidently notice that with the increase in aggregate size, strength decreases, and permeability increases.

For A4.0S5 (M5), the sudden increase in compressive strength is due to the usage of different size aggregates. Here the pore space between the larger size aggregates was filled by the lower size aggregates resulting in high strength but comparatively very less permeability. Thus, the mixture proportions A4.0S2 and A4.0S3 (i.e., M2 and M3) are taken for further studies to examine the effects of aggregate to binder proportions.

5.2 Effect of Change in Aggregate Proportion

The change in aggregate proportion readily affects the workability of mixtures. The mixtures with high aggregate contents are hard to work and the mixtures with less aggregate content are easy to work, have high value of flow index. The effect of change in aggregate to binder ratio in permeability and flow index is given by Fig. 4, and this variance observed was most likely due to an increase in surface tension of the aggregates. From these observations, mixtures with compromising permeability and flow index A4.0S2, A4.0S3, A4.5S2, and A4.5S3 (i.e., M2, M3, M6 and M7) are taken to study the effects of change in fibre proportions.

The mixture proportions are prepared in such a manner by controlling the void content and fresh unit weight to produce less difference in harden unit weight of the samples and to study the exact effect caused by the fibers [22]. The observations

Table 8 Mix designs (with varying fiber proportion for selected trial mixes)

Mix ID	Mix name	Cement (kg/m^3)	Aggregate (kg/m^3)	Water (l/m^3)	Fibre (g/m^3)	Chemical admixtures		Flow (%)	Unit weight (kg/m^3)		Compressive Strength (N/mm^2)		Split tensile strength (N/mm^2)	Flexural strength (N/mm^2)	Permeability (cm/s)
						WRA (g/m^3)	VMA (g/m^3)		Wet	Dry	7 days	28 days			
M10	A4.0S2F1	267	1146	50.6	401	668	802	108	1960	1850	8.63	13.11	1.82	2.91	1.21
M11	A4.0S2F2	267	1146	50.6	802	668	802	103	1975	1860	8.92	13.66	2.01	3.32	1.18
M12	A4.0S2F3	267	1146	50.6	1203	668	802	96	1985	1860	9.06	13.72	2.43	3.45	1.11
M13	A4.0S3F1	267	1168	50.6	401	668	802	104	1980	1855	5.54	8.99	1.6	2.83	1.36
M14	A4.0S3F2	267	1168	50.6	802	668	802	99	1995	1860	6.02	9.87	1.98	3.21	1.2
M15	A4.0S3F3	267	1168	50.6	1203	668	802	93	2010	1870	6.95	9.94	2.62	3.33	1.07
M16	A4.5S2F1	244	1146	46.4	366	610	732	98	1990	1865	11.04	15.11	2.71	2.86	1.34
M17	A4.5S2F2	244	1146	46.4	732	610	732	90	2015	1875	11.61	15.63	3.13	3.24	1.26
M18	A4.5S2F3	244	1146	46.4	1099	610	732	82	2020	1885	12.15	15.98	3.61	3.35	1.19
M19	A4.5S3F1	244	1168	46.4	366	610	732	90	1995	1870	9.96	13.21	2.19	2.79	1.55
M20	A4.5S3F2	244	1168	46.4	732	610	732	81	2005	1875	9.99	13.57	2.45	3.2	1.41
M21	A4.5S3F3	244	1168	46.4	1099	610	732	73	2015	1880	10.13	13.72	2.64	3.35	1.26

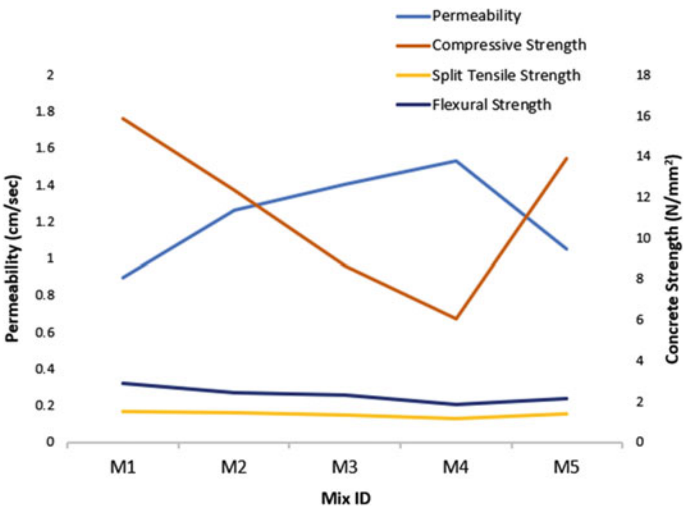


Fig. 3 Effect of change in aggregate size

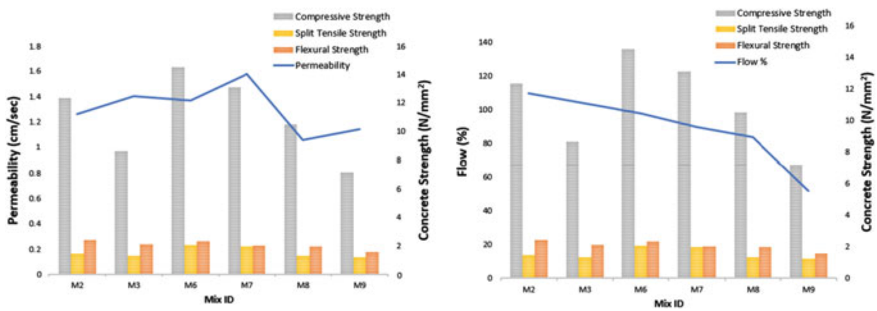
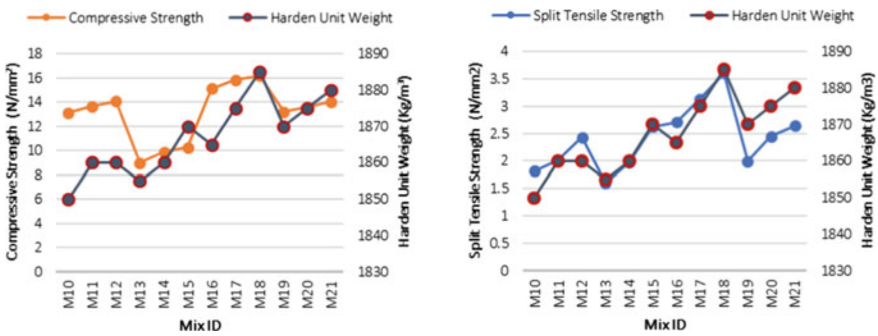


Fig. 4 Effect of change in aggregate proportion

made show that there is an appropriate relationship between the hardened (or) dry unit weight [23, 24] and compressive strength/split tensile strength as shown in Fig. 5a, b.

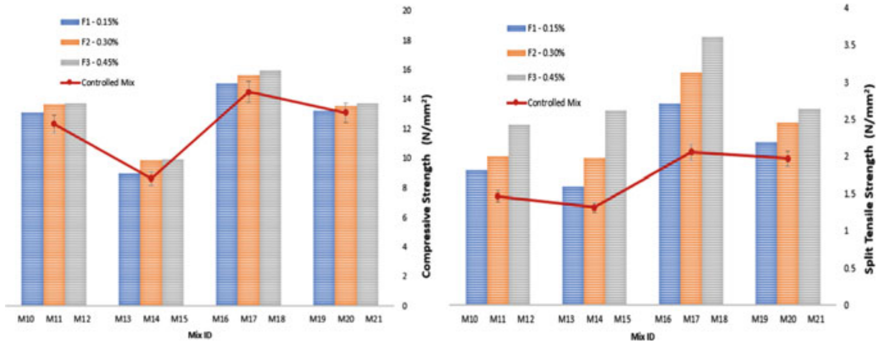
5.3 *Effect of Change in Fibre Proportion*

Mechanical Effects. Based on the reported preliminary test results (Table 5), the four mixtures M2, M3, M6, and M7 were taken for finding the effects of varying fiber proportion F1(0.15%), F2(0.30%) and F3(0.45%). There was no significant change observed in compressive strength values after adding fibre in Fig. 6a, but



(a) Compressive Strength at 28 days (b) Split Tensile Strength at 28 days

Fig. 5 Relationship between harden unit weight and Strength parameters



(a) Compressive Strength at 28 days (b) Split Tensile Strength at 28 days

Fig. 6 Effect of fibre reinforcement in NFC

still, the fibre reinforcement has enhanced the strength gradually to the mixture up to a minimum extent. While considering the split tensile strength, the fibre adds an additional tensile property to the controlled mix (i.e., mix without fibre) Fig. 6b.

Hydraulic Effect. Permeability is the most desirable factor for NFC, fibre reinforcement has a diminishing effect on it. Permeability decreases with fibre content and increases slightly with aggregate size and proportion as shown in Fig. 7 and has a linear relation with hardened unit weight.

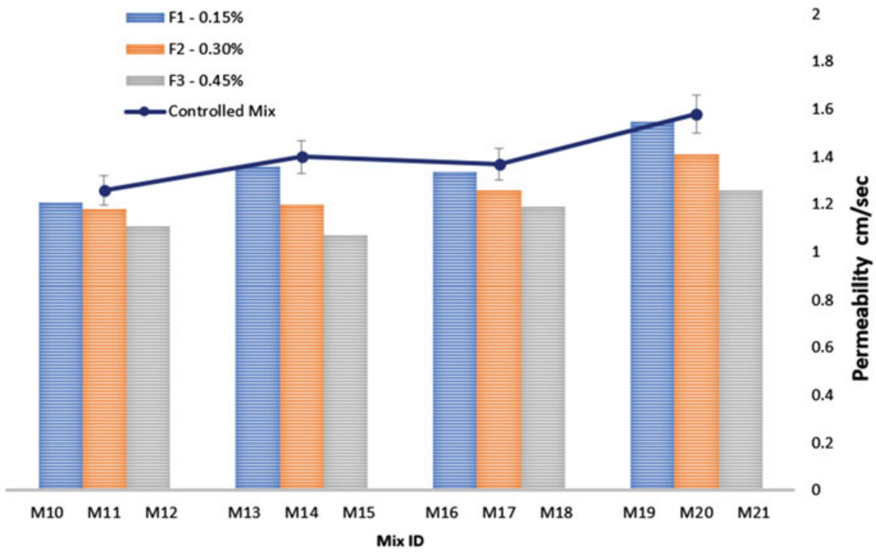


Fig. 7 Effect of fibre reinforcement in permeability of NFC

6 Conclusion

This experimental investigation presents the effects produced on mechanical and hydraulic properties of FRNFC with various experiments such as flow table test, compressive strength test, split tensile test, constant head permeability test.

About 21 mixture proportions (M1-M21) were prepared and studied in detail. The effects of aggregate size and proportions were examined for M1-M9. In addition, the effects of fibre with constant effective length 36 mm and three dosages of proportion (0.15, 0.30 and 0.45%) were tested on the sample mixtures M2, M3, M6, M7, and the following conclusions are drawn.

(1) The average values for compressive strength range from 8.99 to 16.18 N/mm^2 and the average values for split tensile strength ranges from 1.60 to 3.61 N/mm^2. Which is found to be, within the limit as reported in various literature.
(2) The permeability values of FRNFC range from 1.07 cm/s to 1.55 cm/s with respect to the mixture design. Through which, the concrete exhibits pervious behavior, and the values are within the acceptable limit as stated in literature.
(3) This result clearly indicates that both the compressive strength and permeability of FRNFC linearly depend on the dry unit weight of the samples.
(4) The aggregates' size has a significant effect on both structural and hydraulic properties of NFC. The increase in aggregate size increases the pore size and thus the coefficient of permeability, due to the lack of bonding the strength decreases.
(5) The change in aggregate to binder ratio mainly affects the workability of mixtures i.e., the mixtures with high aggregate proportion are hard to work

and for the mixtures with less aggregate content the flow value index increases, and segregation takes place. The variances observed were most likely due to surface tension of the aggregates. However, the water to binder ratio has an inverse effect to that of the aggregate to binder ratio in NFC.

(6) The accumulation of fibre doesn't produce any considerable changes in compressive strength and reduces the hydraulic conductivity of NFC to an insignificant degree.

(7) From the overall observations, the mixture proportion with fibre content had shown a gradual performance compared to conventional concrete.

Finally, it was concluded from the study that polypropylene macro synthetic fibre of 30% and aggregate to binder ratio 4.5:1 for both aggregate size 9.5–12.5 mm and 12.5–16 mm, (i.e., A4.5S2F2 and A4.5S3F2) was the most promising mixture proportion among the various mixtures tested against both strength and hydraulic parameters.

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Disaster Resilience and Rehabilitation in Kerala: A Critical Review of CARe-Kerala's Housing Scheme

Amrita Vinod and Manoj Kumar Kini

Abstract Global warming and climatic changes have an enormous impact all over the world. Kerala has witnessed disasters such as tsunamis, flash floods, landslides, rising temperatures, multi-intensity rainfalls, and heavy downpours in the past few decades. Recurring floods in the past three consecutive years added to the catastrophes amidst the rapid urbanization experienced across the state. This crisis necessitated the government to respond with immediate mass housing solutions for the affected population. However, general methods were not possible in Kerala, across different flood-prone regions with diverse challenges. The traditional approaches cause delays and involve financial losses in the process, also causing challenges in directing funds on behalf of the beneficiaries. Consequently, the Kerala government initiated a novel approach, the CARe-Kerala, CARe-Home housing scheme, which completed 2000 houses by July 2020 (Praveen in *The Hindu*, Thiruvananthapuram, 2020 [1]), across Kerala's flood-prone regions and is continuing at present. CARe-Kerala housing projects, handled by Author[2] and his team, experimented with alternative solutions that can be successfully implemented in specific geographic areas. This paper critically reviews these CARe-Kerala housing projects, which provided disaster-resilient rehabilitation housing solutions during the 2018 Kerala floods. After evaluating the review variables of the assessment criteria relevant to the projects based on its crucial factors and outcomes, the critical review utilizes these factors and the potential success criteria variables to understand various key aspects of the CARe-Kerala housing projects. In essence, this research is an elucidative assessment with a critical examination of the prominent features of CARe-Kerala housing projects.

Keywords Disaster resilience · Alternative solutions · Amphibian houses

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1 Introduction

Climatic changes exceedingly affect nature, and they inflict severe damages on lives around the globe by threatening the vital integrants of health. According to the World Health Organisation, approximately 250,000 additional deaths per year may occur due to climate change between 2030 and 2050 [2]. Because of the same, the environment of Kerala is also altering, leaving the region hazard susceptible and vulnerable to many severe disasters. Kerala's State Disaster Management Plan assesses 39 types of known and reported hazard types in the state that may turn disastrous in the event of lack of proper preparedness and risk reduction planning [3]. Given its location along the sea coast and steep gradient along the slopes of the Western Ghats, the region is prone to hazards such as cyclone, monsoon storm surge, coastal erosion, sea-level rise, tsunami, flood, drought, lightning, landslide (debris flows), land subsidence (due to tunnel erosion or soil piping) and earthquake [4]. Kerala experienced an abnormally high rainfall from 1 June 2018 to 19 August 2018 resulted in severe floods of 2018, and it also reoccurred the next two consecutive years [5]. The vulnerable floodplain settlements face flood water throughout the years affecting the physical and mental health of the population during the ruckus. Realizing adaptation as the solution to the recrudesce situation when the general rehabilitation mass housing techniques fail to serve, the alternate adaptive techniques emerged.

In response to the devastating floods and landslides in 2018, the Government of Kerala took out a large-scale rehabilitation program, CARe-Kerala, in which CARe-Home housing projects worked with no prior models in co-operation with the community. These projects took up alternative and amphibious construction techniques to achieve adequate services and practical solutions. Accounting for the wide acceptance and satisfaction among the public, a critical review of these rehabilitation housing units will exhibit the critical factors, characteristics, and methods implemented to evaluate this novel approach for mass housing projects in Kerala. In the present wavering circumstances of environmental, social, and economic behaviors, adapting to the transformation process using accessible technologies through possible remedies becomes the way to move forward in the rapidly urbanizing Kerala. Moreover, this review intends to scrutinize the unconventional and new approach and its features to pace towards better disaster resilience, rebuilding, and housing in Kerala.

1.1 Aim

To critically review the CARe-Kerala housing projects, CARe-Home, using potential success criteria variables and thorough assessment of the projects' key components.

1.2 Objectives

- To critically examine various elements of the CARe-Kerala housing projects.
- Review the disaster-resilient solutions of the Housing scheme using potential success criteria variables.
- To evolve an evaluation criteria relevant to the projects based on several outputs and evaluation factors critical to the examination.
- To bring out a clear understanding of the novel approach's different aspects to mass housing solutions for Kerala's disaster rehabilitation.

1.3 Research Question

How successful was the novel approach of CARe-Kerala housing projects in disaster rehabilitation, and what factors made the projects widely accepted and appreciated among the communities?

1.4 Methodology

A critical review of CARe-Kerala housing projects, a new approach in the public housing sector, carries out the process in two main sections. The first section intends to review variables of evaluation criteria relevant to the projects based on several key factors, context, and outcomes—these review variables are further set to review the housing projects and understand their features. The second section focuses on evaluating the projects with Potential Success Criteria Variables and inferences from both concludes to the final review outputs.

1.5 Need for the Study

Deciphering Kerala's urbanization profile and disaster vulnerability maps, the presence of high population sprawl in the most susceptible lands alerts the urgent need for alternative and novel interventions to adapt to changing situations and serve the population's needs. Moreover, the general methods opted for mass housing face challenges, such as mismanagement of resources leading to wastage, delay in work, lack of stakeholder participation, and clarity in the process, widening the gap with beneficiaries resulting in lack of satisfaction in the projects. CARe-Kerla housing projects are an attempt to address these shortcomings through a unique approach in this domain. The review of the same to understand its characteristics and evaluate though different potential variables of criticism is a step towards further advancements in disaster resilience and mass rehabilitation housing in Kerala.

2 Background Studies

2.1 Kerala Disaster Vulnerability and Floods

Kerala has a humid tropical climate, with both the South-West (June to September) and North-East (October to December) monsoons being the prevailing climatic phenomena [4]. The steep slopes and rough terrain of the state, broadly classified as highlands, lowlands, and midlands, are hugely susceptible to disasters like landslides, floods. The monsoon storms of high intensity lead to heavy discharges into the rivers and lead to extreme flooding, making floods the most common natural hazard that impacts the state. For some districts, flood-prone areas even cover about 50% of their total area [4], and among them, low lands with high populations have a significantly higher disaster risk.

The Western Ghats is a global biodiversity hotspot with an abundant natural heritage that serves as the backbone of the state's ecology and economy [6], rising on average to 1500 m (4900 ft) above sea level to around 2500 m (8200 ft) [7]. With the monsoon's onset, approximately 1500 km^2 in the Western Ghats are susceptible to landslides and pose a significant threat [3]. Climate change impacts compounds by the state's absence of the adaptive ability to floods, droughts, and mudflows, which increase the disaster frequency and severity. Kerala experienced abnormally high rainfall, 42% above the normal, in 2018, causing severe flooding in Kerala. The state witnessed 482 deaths and 14 lakh displacements of people, and a total of 54 Lakh people were reportedly affected by the floods [8]. Floods reoccurred in the following two consecutive years, crippling people's lives and livelihoods. Unsustainable and weak management of natural resources and low awareness of the changing climatic condition and disaster risks, an absence of risk-informed urban planning, and poorly enforced land-use patterns and practices constitute the main reasons for rapid and unforeseen changes [4].

A large population inhabited the lowlands, and these flood-prone areas of the region frequently face recurring floods in Kerala. Relocation of the people from the flood-prone areas will damage the people's livelihoods, which persuade them to encounter disasters and fall further into physical, mental, and financial distress. These circumstances pose challenges, and adapting and building resilience becomes the need. Thus, the relevance of bringing out alternative solutions using novel methods and techniques arises as an unabated response.

2.2 CARe-Kerala Housing Scheme, CARe-Home Projects

The Rebuild Kerala initiative by the state government, which respond to the 2018 floods, included CARe-Kerala projects to rehabilitate the flood-affected population. The CARe-Kerala Scheme consists of three projects: CARe-Home, CARe-Loan, CARe-Grace, in which CARe-Home envisages 1500 first phase houses and 2500-s phase houses with a cumulative outlay of 200 crore rupees, entirely funded by contributions from the Member Relief Fund of the co-operative sector [9]. The projects emphasized resilient modules utilizing alternative methods and construction techniques. With the Rebuild Kerala initiative's co-operative alliance, the projects employed Kerala's co-operative department's extensive networks of 15,624 co-operative societies across the state for the projects. Eighteen proposed designs were encouraged to address the problems raised across the state's 131 blocks and benefitted 61.17% [10] of the below poverty line population.

3 Overview of the Review

The critical re-evaluation of CARe-Kerala housing projects is divided into two main sections. The paper, "Approaches to evaluation of affordable housing initiatives in Australia" [11], refers to significant elements of housing evaluation which can be broadly summarised to—the context, including the general issues, site conditions, and major stakeholders; design and methodology; process and participation, impacts and benefits evaluation and the financial viability and effectiveness. Moreover, the case-study analysis of the National Housing Corporation of Kenya low-income housing projects [12] also refers to social response or the ontological depths of housing and their outcomes. The projects are scrutinized based on execution, technologies, materials used, financial transparency, user satisfaction, participatory process, and practices to tackle challenges in the first part, considering the features of the CARe-Home projects and the evaluation factors. The second examines the projects using 13 Potential Success Criteria Variables employed in "Evaluation of Critical Success Criteria for public housing projects in Nigeria". [13] to evaluate public housing projects.

Definition of Potential Criteria Variables [13]:

- **PSC 1, Overall Project Cost**—Final cost of the overall project.
- **PSC 2, Cost of Individual house units**—Final cost for individual housing units.
- **PSC 3, Overall project duration**—Time taken to complete the project.
- **PSC 4, Rate of delivery of Individual housing units**—Time taken to deliver individual house units.
- **PSC 5, Overall project and individual house quality**—Quality of project, including associated infrastructure.
- **PSC 6, Overall Client satisfaction**—Satisfaction of client with overall project outcomes of individual house unit.
- **PSC 7, Extent of admission of natural ventilation/lighting on individual housing units**—The extent to which natural ventilation and lighting are incorporated into the design.
- **PSC 8, Overall risk containment**—The extent to which risks can be contained, minimized, or managed on the project.

- **PSC 9, Overall/ individual house unit environmental impact**—Impact of construction waste, environmental degradation, pollution, and waste from individual house units on the general public.
- **PSC 10, Health and safety measures with individual house units**—Health and safety hazards posed by the living environment, materials, and construction practices.
- **PSC 11, Technology transfer/Innovation**—The extent to which new technology significantly improves the design and construction of living space by decreasing installation cost, increasing performance, improving the construction process applied, and integrating local artisans.
- **PSC 12, Higher use of Local Materials**—The extent to which local materials are used to reduce cost/ make it affordable.
- **PSC 13, Easy and Cheaper to Maintain**—The ease and cheapness to carry out maintenance over time.

3.1 Features of CARe-Kerala Housing Projects

Method of Execution. CARe-Kerala housing projects opted for a co-operative practical approach, a novel step. Kerala's co-operative department, a web of primary co-operative societies, indulged in the flood rehabilitation and mass housing project in 2018. The state-level project implementation Unit (PIU) was formed to implement the projects, which constitute the Kerala co-operative department secretary, local government departments, revenue department, and primary co-operative societies [10]. Further, under the district collector, each district exercised an implementation committee for the project operation. However, the execution is carried out through co-operative institutions, as authorized by the PIU. A committee chaired by the chairman of the Uralunkal Labour Contract Society—a reputed co-operative agency with experience in undertaking large-scale public projects—constitutes the technical advisory unit for the project operation with the director of the Co-operative Academy of Professional Education (CAPE) as the convener of the team (Fig. 1).

The District nodal officer is responsible for the project implementation, and the resource group formed for the projects provides inputs for supporting the project. At the Implementation Agency level, the beneficiary committees were established with the chairman and other concerned members of the Governing Board of the selected co-operative society, the secretary of the society, the beneficiary, and the representatives of the District Collector and Grama Panchayat [10]. This committee works with an institutional system, exercised from the central body, reaching the grassroots level, bringing out the most beneficial solutions through co-operation and discussions. Methodical and meticulous planning ensured quality services on time with reduced misuse of resources achieved through efficient progress strategies, systematic arrangements, and activity dispositions according to resource availability and time constraints for completing the project.

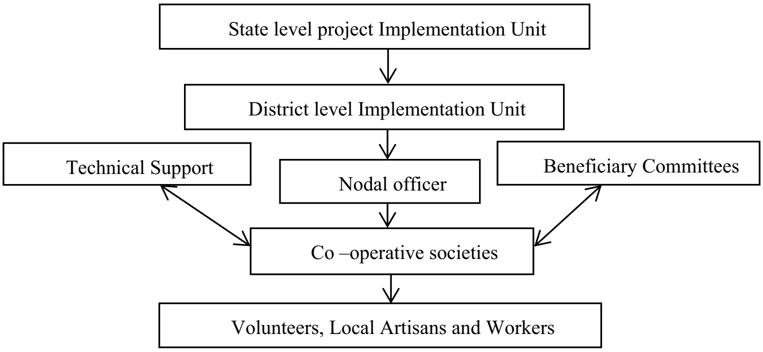

Fig. 1 Method of execution, CARe-Kerala housing projects. *Source* Author

Fig. 2 Residence at Karthikappalli, Alappuzha, Kerala. *Source* Author[2]

Technologies and Materials. The committee for technical support and advisory provided appropriate interventions on the diverse terrains of construction to ensure maximum efficacy and safety with optimum resource consumption. For instance, enabling modifications that created pillar-built light-structured houses, well-based pillar structures to combat the instability of loose clayey soil, and two-story valley-side houses on exceedingly small plots [10].

The modular units employed in the design (Fig. 2) achieve faster and more efficient construction without compromising the quality. The aluminum fabricated window

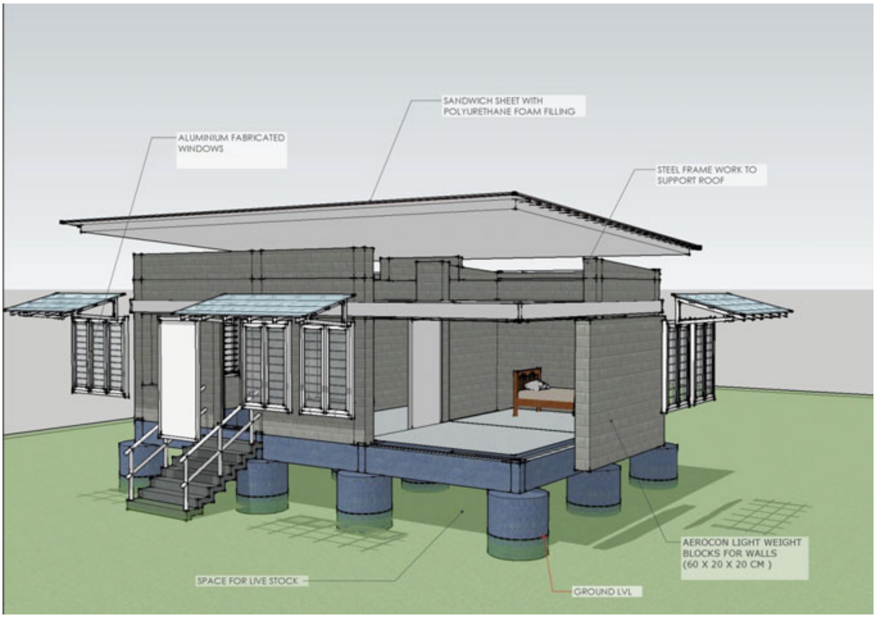

Fig. 3 Residence at Karthikappalli, Alappuzha, Kerala. *Source* Author[2]

(Fig. 3) is one of such elements employed to accomplish this goal. Moreover, modular construction techniques support modified uses in the future, which can also be easily dismantled, transported, and re-assembled on a different site. The project used lightweight components such as AEROCON blocks to construct walls and partitions, sandwiched sheets, and polyurethane form filling used for roofing with steel-frames supporting the structure deviates from the conventional construction materials.

Practices to tackle challenges. CARe-Kerala projects focused on on-site responsive solutions that are adaptable and stable on the landscapes, ranging from flood-prone low lands to high range valleys with restricted land area and location choices. The plasticity and freedom of designs broke the uniformity and facilitated appropriate design innovations and interventions according to the site conditions. The concrete rings (Fig. 4) used to adjust the foundation height of the housing unit in the flood-prone site is such a flexible design intervention.

Financial Transparency. Structured mechanism of financial management supported the project to ensure proper accounting and transparency. Initially, the project was built with an allocation of five lakhs rupees per house, constituting four lakhs from the mobilized fund by Co-operative Department through donations from banks and societies. The State Disaster Response Fund allocated a sum of 1, 01, 900–95,100 rupees per house, and a few projects gained additional local fund mobilization at various construction stages [10]. Beneficiary committees discuss and utilize the fund allocated through clear accounting strategies with periodical monitoring. Moreover,

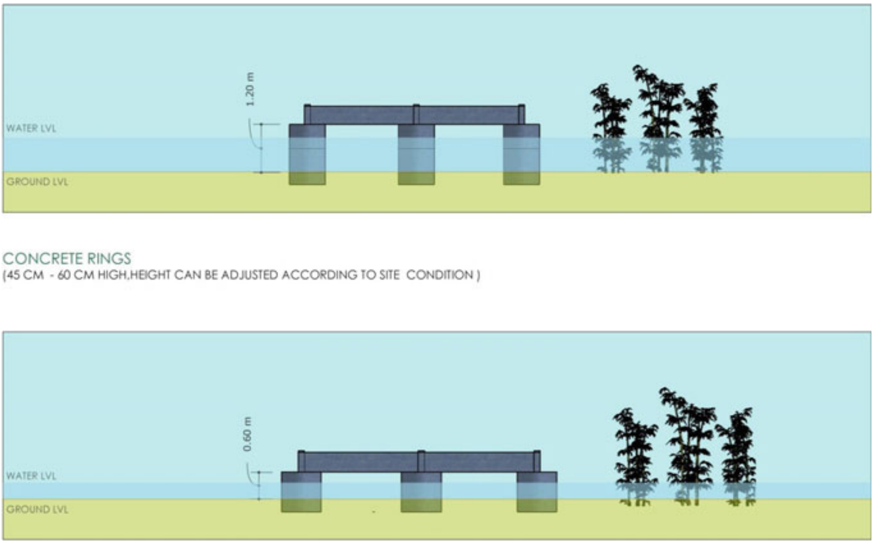

Fig. 4 Concrete rings (foundation) in flood-prone areas. *Source* Author[2]

the local support groups (mainly from schools, religious institutions, political parties, local governments, community development societies, relatives and family support, NGOs, and business enterprises) raised additional funds. Work progress and funds are checked periodically and are audited by the co-operative bank auditors. The co-operative framework of fund management facilitated voluntary contributions with transparent operations and eliminated misuse of funds (Fig. 5).

User Satisfaction. CARe-Kerala housing projects succeeded in incorporating the flood victims' needs regardless of their age and circumstances. Three-quarters of the total projects varied between 600 and 400 ft^2 of plinth area [10]. 80% of the beneficiary families have a new house with a greater plinth area than their previous one, improved resilience and safety factors, and a sense of protection and ownership [10]. Gopalakrishnan from Alappuzha reported that he is satisfied and no longer fears floods as he procured a flood-resilient house [1] under the CARe-Home project. In 90% of the cases, the initiative provided beneficiaries with new homes in the areas of their original homes [10]. Due to this strategy, no disturbance to livelihoods occurred and created adaptable and safe solutions for resilience in future catastrophes. Efforts

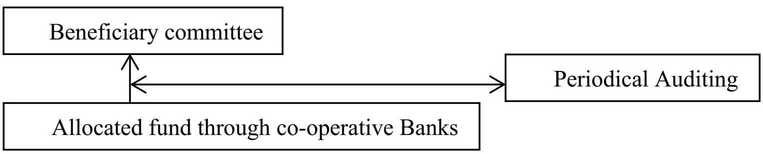

Fig. 5 Financial flow, CARe-Kerala projects. *Source* Author

for inclusive progress focused on vulnerable sections [10]. The staff of co-operative societies, Kudumbashree (the Kerala State Poverty Eradication Mission), and NGOs appreciated CARe-Kerala housing projects. Several officials involved in the projects also expressed satisfaction and happiness in their work as it has been the first of its kind in their service life. The merging of the project with existing schemes, including the localities in collaborative works, earned trust within the community for delivering quality work within the stipulated time with complete satisfaction.

Participatory Process. The exemplary participatory process devised in CARe-Kerala included volunteers, students, and teachers from State Engineering Colleges, local artisans. Besides, two students each got continuously engaged with each house, utilized academic resources, and developed skills and social responsibility. The convergence with Mahatma Gandhi National Rural Employment Guarantee Scheme (MGNREGS) assured on-site workers for 90 working days [14]. Under officers with the construction responsibility in the co-operative department and local co-operative society, the participation of local governments, elected officials, NGOs, religious groups, and political parties created a favorable co-operative environment throughout the implementation process [10]. The additional resources mobilized, including cash and voluntary work, raised the average overall cost (more than 100,000 rupees/house). Unlike other mass housing projects, the co-operative societies were involved with high enthusiasm. These projects with proper division of responsibilities among the stakeholders were widely accepted among people. The teamwork and unity procured with active social interaction developed an emotion of togetherness, safety, and ownership within the community. Thus, the work quality and satisfaction at the completion stage get invigorated substantially.

3.2 Evaluation Using Potential Success Criteria Variables for CARe-Kerala Housing Projects

PSC 1, Overall Project Cost—The completion of 2000 houses in the first phase across the state by July 2020 [1] has the total sum spent to about 118.82 crores with multiple outlets resulted in additional fund mobilization; own donations and those contributed to the kitty by individuals and agencies [10].

PSC 2, Cost of Individual house units—On average, this lifts to about 619,842 rupees per house, compared to the initially expected expenditure of about 500,000 rupees per house, which included mobilized funds of four lakhs from the Co-operative Department and around one lakh by the State Disaster Response Fund.

PSC 3, Overall project duration—CARe-Kerala housing projects were initiated soon after the floods of 2018 and completed 231 new houses [15] under CARe-Home project by February 2019. By July 2020, CARe-Kerala housing scheme, CARe-Home, achieved its first phase of 2000 houses.

PSC 4, Rate of delivery of Individual housing units—For the beneficiary families identified from the list of flood victims prepared by the District Collectors and Disaster Management Department, 2000 houses were delivered across the state by July 2020—CARe-Kerala housing scheme.

PSC 5, Overall project and individual house quality—Climate and site-responsive resilient housing of CARe-Kerala ensured user satisfaction and essential services. Usage of lightweight materials, innovative technologies, and local resources with user participation checked the desired quality.

PSC 6, Overall Client satisfaction—User satisfaction at all phases of projects is one of the primary focuses of the collaborative approach through the beneficiary committee, including the client as one of the major participants. Change of paradigm from relocation to adaptation in CARe-Kerala housing scheme eliminated the challenges such as unemployment and disruption of livelihood source.

PSC 7, Extent of Admission of natural ventilation/lighting on individual housing units—Every housing module ensured adequate natural ventilation and lighting, maximum utilization of available area, and experimented with better—resilient housing solutions tackling the sites' challenges.

PSC 8, Overall risk containment—Floods are the most recurring disaster that affects construction in the past three years. CARe-Kerala addresses this challenge without relocation through adaptive and resilient construction techniques. Thus, the risk factor decreases, making the living environment resilient to future catastrophes.

PSC 9, Overall/ individual house unit environmental impact—Modular components enable easy maintenance and dismantling for re-construction elsewhere. Environmental impact is considerably low compared to conventional housing methods.

PSC 10, Health and safety measures with individual house units—CARe-Kerala housing projects put the users' safety and health as a vital consideration of the rehabilitation process. Design elements such as the concrete rings used to increase foundation height in flood-prone areas exemplar this aspect.

PSC 11, Technology transfer/Innovation—The technical advisory and support from students and teachers of State Engineering Colleges collaborated in the projects. The liberty to deviate from the conventional methods substantially increased its efficiency and functionality through innovative approaches.

PSC 12, Higher use of Local Materials—Compared with the former housing initiatives, CARe-Kerala housing projects consider local materials and resources suitable for site-responsive solutions. However, resilient housing in future catastrophes held the primary focus of the resilient public housing initiative.

PSC 13, Easy and Cheaper to Maintain—Adaptable constructions that can be cheaply maintained were significant for the projects. Modular building units such as aluminum fabricated windows, and AEROCON blocks enabled easy construction, transportation, re-construction, and maintenance over time.

3.3 Inferences

With defined and distinct implementation strategies on an institutional structure, CARe-Kerala housing projects exhibited collaborative nature by gaining broad stakeholder engagement, technical advisory, support from local communities and organizations, local resource mobilization, and successful and satisfactory completion time. Co-operation within and between the responsible groups, the beneficiary committees at different management levels, encourage sufficient voluntary efforts, including NGOs, students, and teachers from the State Engineering Colleges. Top-to-bottom development structure decreases the total expenditure by approximately 25–35% and uses cost-effective methods, systematic inspections, and appropriate changes, assuring a better quality of work. CARe-Kerala housing projects solved many challenges faced by the general mass-housing methods, such as the gap between the designers, workers, public, beneficiaries leading to unsatisfactory and incomplete projects, non-systematic management and loss of time and resources, compromised design due to various influences, and the non-context responsive design affecting the overall output quality. However, by devising a collective approach through extensive co-operative society networks, the projects created a platform ensuring beneficiary participation and arriving at the best possible solutions with the present circumstances and available resources. These participatory operation methods revealed every stage of construction, leveling out financial transactions, resources, and work completion, making them transparent and effective throughout the project. Two–way benefits of collaborations such as the academic co-operations utilized the academic resources and built skills, social awareness for future professionals; local support and participation create a sense of ownership and responsibility, improve satisfaction, and gain wide acceptance among the public. The co-operative society networks proved to be a successful medium of operation for CARe-Kerala housing projects, a novel approach of alternative solutions, with its extensive networks and communication all over the state.

4 Conclusion

Review on CARe-Kerala housing projects unfolded a collaborative and inclusive approach through co-operative societies, a novel model, towards mass rehabilitation housing in Kerala. Notable features of these projects have substantially elevated housing quality and increased stakeholders' satisfaction after the project completion. The distinct methods of execution, technologies, and materials used, financial transparency provided through the co-operative bank networks across the state, and the overall user satisfaction, participatory process, and practices mark the novel approach as an effective, practical, and successful rehabilitation housing project in Kerala. Examining CARe-Kerala features, using the evaluation variables and potential success criteria variables, also reveals the projects' distinct and vital initiations. The characteristics and the widely accepted outputs set CARe-Kerala housing projects, CARe-Home, among the most successful and appreciated housing projects across the state. This initiative is evidence of evolving dynamic co-operative responses in the state and is a remarkable model that can be emulated elsewhere in the future.

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Community Resilience Measures

Measuring Disaster Resilience at Community Level and Exploring the Prospects of Revitalizing Communities Coalescing Disaster Risk

C. A. Bindu and Subha Vishnudas

Abstract Increasing the efficiency of disaster response, discouraging development in vulnerable areas and increasing the resiliency of community towards disasters are the three major ways of dealing with disaster risk reduction and mitigation. The paper focuses on the third method of enhancing disaster resilience at community level where community in the broader sense includes family, neighborhoods, panchayats, towns and cities. Though this is the most difficult one as the factors contributing to the increased or diminished capacity of a community to resist, absorb or restore the pre-disaster state has to be measured, evaluated, benchmarked and also assessed and compared across space and time. Several international organizations have put enormous effort and have devoted abundant resources in building resilient communities. Investing in Disaster Risk Reduction is one of the main thrust among the four of Sendai Framework for Disaster Risk Reduction (SFDRR). The application of resilience can lead to transformation of communities as the concept of resilience can encompass different disciplines with same purpose. A resilient community can be built by revitalizing its pillars (Social, Economic, Environmental and institutional), likewise revitalization projects also helps in building up a resilient community, which has well been exemplified in various cases where different strategies of revitalization has led to disaster resilience of communities. Enhancing the disaster resilience of a community or revitalizing a community, both requires political will, strong leadership and institutional capacity. The paper concludes by establishing that coalescing disaster risk into development activities contributes to long term endurance, resurgence, resilience and revitalization of the community.

Keywords Community resilience · Revitalization · Disaster risk reduction

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1 Introduction

Increasing the resilience of the community became recognized as one of the major ways of dealing with disaster risk reduction along with increasing the efficiency of disaster response and bringing development control measures in vulnerable areas. Therefore, in order to explore the possibilities of coalescing disaster risk in revitalizing communities, it is highly important that we understand the concept, definitions and meanings of Urban Resilience and Urban Revitalization, their dimensions, interdependencies and inter linkages. Though both concepts intervene in blighted areas (reasons may vary) and have the common goal of betterment of the society, little work has been done integrating these concepts. Hence, the paper seeks to answer two questions-How can resilience be measured in a society? And how does enhancing the resilience of a community contribute to the revitalization of an area? The paper explores the concept of resilience and analyses the available methods to measure community disaster resilience and establishes how methods to enhance resilience can lead to revitalization of the place. Along with the concept and dimensions, the strategies used for revitalization is also studied and the analogies and variances of both the concepts is explored. The purpose of this study is to explore the possibilities of interlinking the concepts so that any revitalization project will help to enhance the resilience of the community and any attempt to enhance the resilience and mitigate disaster will have an added benefit of revitalizing the place itself.

2 Resilience and Measuring Disaster Resilience

There is no universally agreed definition on community resilience [1–4]. The malleability of the concept is depicted as its strength as well as weakness. The multiple meanings and interpretations of resilience portray the popularity of the term and the range of fields it is used [5]. The definition of resilience has evolved over the years and is still evolving and is constantly redefined [2]. After the adoption of Hyogo Framework for Action (HFA) 2005–15, there was a shift in vulnerability assessment method and the 'resilience-based approach' became more popular [6]. Subsequently, there was a proliferation of definitions on resilience by various authors and organizations globally and several international organizations devoted abundant resources in building resilient communities.

Among the many popular definitions of resilience, the one given by Walker et al. (2004) and cited by most authors is, 'the capacity of a system to absorb disturbance and reorganize while undergoing change so as to still retain essentially the same function structure identity and feedback' is often designated as resilience [7, 8]. Being resilient also means the ability to grow and improve in the face of hazards [9] and it is only in a resilient system there is opportunity for growth and development, renewal and revitalization.

The literature study reveals that a consensus has not been reached regarding the measurement of resilience and the volume and complexity of issues related to disaster reveals that a reliable measurement of resilience is not possible until a community has experienced a disaster and has recovered from it [10]. Though post disaster recoveries are too often addressed, planning for future disasters or measures to be taken by the community to face future disasters are seldom communicated. The assessment of resilience should also take care of the asymmetries within it, among different groups and individuals of the community. This denotes that the social capital and the vulnerability along various cross sections of the community need to be focused.

Though the method for assessing community resilience is not fully developed [11] and remains a challenge [12], the factors contributing to the increased or diminished capacity of a community to resist, absorb or restore the pre-disaster state has to be measured, [8, 11, 13] evaluated. Therefore, a framework that is capable of addressing these is needed rather than a technical apolitical framework. These frameworks can either be standardized or tailor made to the context in which it is used or it can be a combination of both the methods. The former method can be used in any country as those works on generalized assumptions whereas the latter takes care of the local conditions. When framing the resilience frameworks, all the mutually reinforcing dimensions of resilience fail to get included. The technical and political interpretations get highlighted while ecological and social aspects often take a backseat. A typical example has been found in the post disaster interventions in New Orleans following hurricane Kathrina [14].

2.1 Scales of Measurement

Scale is important in expressions of resilience [15]. The geographical scale varies from global level to individual level. Global level is the highest level of measurement. National level or country level is the common high level of measurement. Examples are Hyogo framework for action, Global focus model, prevalent vulnerability index, etc. Sub national or community level measurements are taken in three forms. It can be using political boundaries (District, Panchayats), distinguishing rural and urban (Cities, Towns) or defining a geographical area. Examples being Resilience Capacity Index, Baseline Resilience Indicators for Communities (BRIC), ResilUS, etc. Household or individual level is the smallest level or smallest unit of analysis. Example, Community-Based Resilience Analysis (CoBRA) [4].

2.2 Characteristics of Measurement

Disaster resilience can be measured in different ways. The approach adopted for measuring depends on the elements included in measurement, levels of measurement, the dimensions of resilience included and the smallest unit of analysis taken. The appropriateness of measurement in a context depends on the elements of disaster resilience included [4]. The measurements of resilience capacity tracks inputs (Govt inputs, inputs from community, sector or firms, household themselves), Outputs (reduction of exposure to disasters, vulnerabilities, resilience capacities and actions), Outcomes (actual losses or modeled losses base on probabilities) and impact (degree of well being maintained despite disasters) [4].

Resilience measurements can either use standard metrics, context specific metrics or a combination of both. Standard metrics are not flexible and fail to capture local conditions and circumstances. Context specific metrics are tailored to countries, communities, households or individuals. Example, National Response Coordination Center (NRCC) in Nepal andCommunity Disaster Resilience Index (CDRI) for coastal communities of US. A combination of both contains set of standard indicators with additional locally tailored measurements. Example, Community Based Disaster Resilience (CoBRA), Rural Resilience Index (RRI). Tailored measurements can be deduced using participatory processes.

2.3 Dimensions/Capitals

The major dimensions included in measurement of resilience of a community are Social, Economic, Human, Physical and Natural. These dimensions have been described as Community Capital [6]. These capitals portray the relationship that exists between individuals and their larger neighborhood. The most common capitals discussed in all literature include capitals namely Social, Economic and Natural, though Physical, Institutional, Political, Human capitals are also widely discussed capitals.

Economic capital indicates financial resources of the community. A stable or growing economy implies enhanced resilience whereas a community with declining and unbalanced economy implies increasing vulnerability or decreasing resilience. Economic capital can be measured through income, savings, investments, property, value, employment, etc., [6]. All the various earth systems comprising of atmosphere, water systems, soil and land, biologic and climatic are included in environmental capital, which is also referred to as natural capital. A healthy environment capital will contribute to other forms of capital. It refers to an eco system that has unpolluted air, water and soil. It is measured through air quality, water quality, soil quality wetland, forest, bio diversity, parks, etc., [6]. The four basic functions of environmental capital are regulation (that keeps our ecosystem in balance. Example, ozone layer), carrier (which provides space for human habitation, agriculture, production and recreation activities), production (what environment gives beyond basic subsistence Example, materials for building and manufacturing, fuel and energy) and information (includes varied perspectives of aesthetics, heritage, culture and science) [16]. Physical capital majorly refers to public structures which are always under the threat of destruction due to exploitation. The quality and location of the Physical capital is very important and it includes all physical and social infrastructures including residential buildings, public buildings, bridges, dams, canals, etc., [13]. Physical capital gains strength when the community has a strong human, social and cultural capital [17]. Human capital which is both innate and accumulated is one that enhances human labor productivity as it denotes skilled and trained working age population [6]. Additional to education and skills human capital also includes physical and mental health, emotional stability, etc. Enhancing human capital can be accomplished through institutions like schools, churches, recreation centers, community gathering spaces, etc., that will also support in building community cohesion [17]. Human capital is measured through educational status, health, dependence ratio, housing quality, etc., of the community which is also a prerequisite for capacity building and economic development.

The literature study reveals that the Social, Economic and Environmental capitals are critical to resilience of a place. The resilience of a community depends on the balance of its different capitals. The energy of one capital definitely affects the other forms of capital as all these are inter related, some deep and some subtle. Example, depletion of fishes can cause serious concern to social and economic capital of fishermen community [17].

The researcher has come across more than one hundred resilient assessment works in the literature study of which 25 popular assessment efforts were selected for detailed study based on the agency supporting the program, the year in which the effort was started, the context in which the framework was developed and the assessment method used, the location of study area and the scale of the study. The study revealed that the context of the study was majorly hazards to climate change, floods, hurricanes and cyclones followed by draught and earthquake. The majority of toolkits and indexes are to measure resilience at community level, though national and city level is not uncommon. It was also observed that the majority of tools were developed and applied in United States. Indonesia, Philippines, Thailand and India are other countries were assessment tools have been applied at city level and community level.

The majority of frameworks were developed using participatory method in which an initial set of indicators were developed, which was then modified by reaching a consensus with the stakeholders and expert group opinions. After the indicators are finalized, weights are assigned to each to assess the resilience of the community, except ‘BRIC’ and CCR-2, which solely depended on literature study. Very few frameworks were developed using public opinion and hence local needs and aspirations are not reflected in any of them. Currently there is no overarching method to develop a framework integrating literature framework and stakeholders and experts perceptions. Thus developing a new framework using a participatory approach has become the need of the hour.

3 Resilience and Sustainability

The concept of sustainability has shifted over the years. From 1960s to 70s the environment, society and economy was studied as separate disciplines, from 1970s to 1990s the emphasis was given to the interdependency of environment, society and economy and from 1990s to 2000s a dynamic model was evolved from a more static model. The concept of resilience, which is fundamentally the socio-ecological capacity to resist, cope and adapt to changes was incorporated into the linkages and dependencies of the three pillars of sustainability- Environment, Society and Economy to make it a more ideal scientific model. Resilience was first discussed associated with sustainability at 1st world summit on sustainable Development at Johannesburg in 2012, where the focus was on managing current resources assuring the welfare of future generations. Later resilience studies was considered as a necessary approach in building sustainability and started emerging in various sustainability debates and different policy domains as well [18]. According to Bene et al. 2014 the concept of resilience became the central criterion for many disciplines replacing sustainability as the ultimate objective of development. It is argued that in SDG goal 11, the concept of 'resilience' was poorly and too narrowly defined [19].

Resilience and sustainability are two distinct concepts positively correlated, though sometimes used interchangeably [19]. They are not mutually exclusive but are interwoven to transform the future towns and cities [20]. The world summit on sustainable Development at Johannesburg in 2002 asserted that both the concepts sustainability and resilience have certain common principles like precaution against overuse of resources, restraint from vulnerability and fostering ecological integrity [18]. Many authors have presented resilience as an important and crucial component of sustainability [21, 22] that works in the context of long term sustainability objectives [20]. Sustainability is increased resource efficiency and a sustainable community is one which strives to maintain a high quality of life, absorbs and adapts to internal and external stresses and persists through time with a healthy and thriving society, environment and economy [23]. Chellari et al., quotes Holling and Walker, 2003 that a region that is economically, ecologically and socially sustainable is also a resilient region.

4 Concept, Definition and Strategies Used for Revitalization

Every city grows through changes and development. Planning interference becomes inevitable as city grows, matures, becomes old, undergoes physical decay, gets struck with disasters (both natural and manmade) and becomes unfit for residential or business use as time passes. As time passes the existing land use may become incompatible with the surrounding land use. For example, the commercial area may expand into residential area, factories and prison built long ago can now be in the middle of the city, schools may be now situated in busy streets, there may exist outdated water supply lines and sewage and drainage line becoming detrimental to the modern society. These are common phenomenon that happens in a city. Hence to bring back the old vitality, improve or maintain the quality of life revitalization, regeneration, renewal, etc., becomes inevitable.

The meaning of revitalization according to Oxford dictionary is to impart new life or vigor. It also means ‘Bringing again into activity and prominence’. It is the process of infusing vitality into areas that are judged to be in some way substandard. Revitalization means the physical development of blighted areas by improving the local infrastructure, creating additional jobs and may also involve elimination of undesirable business and groups [24]. According to Ujwala and Priya [25], urban revitalization is the process of rebuilding thriving economically, environmentally and socially sustainable urban areas and population, in areas that have been in decline. The goal of revitalization of degraded areas is not only to stop the deterioration of urban areas but also to rebuild the city, strengthen and enhance social cohesion, improve economic activities, provide good quality environment, provide adequate recreational facilities, regenerate historic centers and urban services and improve the quality of life [26, 27].

Though various strategies are used for revitalization of towns and cities, the most popular one is the ‘cultural development strategy’ that played a major role in the development of towns and cities, despite its size and demographic profile. The cultural activities and events facilitate to bolster a city’s or town’s image, attract tourism and foster economic development, and thereby museums, performing centers, conventional centers, galleries, etc., are built as a part of wider urban-regional development and revitalization strategy. The Cultural development can be achieved in multiple ways and hence can be grouped into three based on strategy goal, focus and target audience. They are entrepreneurial strategies, creative class strategies and progressive strategies. In entrepreneurial strategies, the brand identity of the city is reinforced and a proactive market driven approach is pursued, guided by solely economic objectives. Creative class strategies seek economic development through the provision of quality of life and providing recreational amenities to attract the creative class which includes software engineers, artists, architects, writers, etc. Progressive strategies follow a more grass root and neighborhood-based approach where local community needs and their cultural aspects are addressed ensuring equitable access to cultural resources [16].

Human investment strategies aim to improve the peoples capacities especially of youth and children by investments in human capital, job training, education enhancement, mentoring and internship, career counseling, etc., targeted to the unemployed and underemployed in order to give those individuals the necessary skill in the increasingly service oriented economy. The key process is to build human capital in deteriorated cities and create an infrastructure of support for disadvantaged. Example, Baltimore and New Orleans in US had made this strategy the foundation of all its revitalization efforts [28].

Downtown revitalization encompasses a wide range of individuals and activities. Therefore, it requires cooperation and funding from a multitude of sources like local government, chamber of commerce, private sectors, civic organizations and other key institutions. Downtown revitalization should include new housing and commercial businesses, after school programs, anti crime initiatives, youth development and employment services, arts, recreational opportunities and public transit and many more.

5 Interdependencies and Inter-Linkages of Concept of Resilience and Revitalization

According to a study conducted by Schreurs and Miranda in 2021, the city also needs informed people and trained specialists apart from the support of a strong government in order to achieve a sustainable resilient revitalization plan. A framework called Sustainable Resilient Urban Revitalization (SRUR) framework was developed to renovate the existing residential buildings in a historic district wherein the respondents' awareness of sustainability and resilience, prioritization of dimensions and promotion strategies were evaluated through Delphi method.

Tables 1 and 2 depicts the analogies and divergences of the concept of resilience and revitalization respectively. Table 1 discusses the similitude of the concepts, dimension, intervention areas, scale of the projects, approach followed, major strategies used, time scale of action, acceptance level of the concept, dependency and the final goal and outcome. Table 2 distinguishes resilience and revitalization conceptually even though the end goal and outcome are one and the same.

Table 1 Analogies in resilience and revitalization concepts

Characteristics	Similitude
The concept	Both the concept implies imparting new life, strength and vitality to an area or neighborhood
Dimensions	Both concepts are multi dimensional. The common dimensions of resilience and revitalization are social, economic, environmental, physical, institutional and human
Intervention area	Both concepts are applied in blighted areas and work on regaining the functionality
Scale of the project	Varies widely spatially
Approach	Bottom up interventions required as each community is unique having its own history, geography, culture, etc.
Major strategy	Public and private partnership, especially for physical development or infrastructure improvement
Time scale of action	Long term process, yet involves short term goals
Acceptance level of the concept	Both concepts are portrayed as positive desirable process
Dependency	Social capital/ neighborhood networks
Goal and outcome	Positive livelihood outcome –building a cohesive inclusive community

Table 2 Divergences in the concept of resilience and revitalization

Resilience	Revitalization
Emerged in 1973, but became popular only after 2000	Emerged in 1970s
Varies widely conceptually and spatially. Disaster resilience is the most popular one though other narrow forms of resilience also exist	No wide variations. It is the process of infusing vitality into sub standard areas, though emphasis is given on conserving identity, culture, etc.
Ability to bounce back after a stressful event	Bringing back again into activity and prominence
Speed of recovery or transformation is important	The temporal scale of revitalization is not so important
Arguments on the limitations of resilience are that the concept is complex and difficult to operationalize	Though revitalization is a broad concept with wide implications on all sectors, mostly practiced in a smaller area (core areas or along a stretch)

The application of both resilience and revitalization requires thorough analysis of economic, social, environmental and human aspects. The economic analysis includes the financial resources, livelihood pattern, employment and unemployment status, economic vitality of the community, education and health. The social analysis includes social capacity, social wellbeing, social cohesion, community facilities, affordable housing status and literacy level, extend of participatory planning, etc. The environmental analysis includes the natural resources, biodiversity, integrated solid waste management, etc. The human capital looks into the physical and mental health and the emotional stability of the dwellers. These inputs when combined with external drivers of change like policies, risk reduction strategies, progressive revitalization strategies, etc., along with internal drivers of change like availability of resources, inherent resilience capacity of the community leads to the desired outputs like economic development, physical improvement, social upliftment, environmental protection and cultural enhancement that reinforces the fact that disaster risk reduction and mitigation strategies and enhancement of community disaster resilience can lead to resurgence and revitalization of the area (refer Fig. 1).

6 Revitalizing Communities Coalescing Disaster Resilience

Increasing disaster resilience can lead to a new path in which the responsibilities as well as the merits of resilience are distributed within the community. This calls for incorporating resilience in our public policies. Only when a disaster strikes a community or country, these policies with broader goals and visions, surface to forefront that too only with a strong political will and leadership [10]. Example, in Fukushima, Japan the160,000 evacuees in 2012 had reduced to 43,000 in 2018, when

Fig. 1 Schematic diagram showing the interdependencies and interlinkages of Sustainability, resilience and revitalization concepts. *Source* Author

Fukushima prefecture issued a vision for revitalization which stressed on safe and secure sustainable society free of nuclear energy. Subsequently, the share of nuclear energy in its electricity mix reduced from 30% in 2011 to 6% in 2020 added by a dramatic shift and development in alternate energy sources. Today Japan has the largest installed photovoltaic capacity in the world [29].

7 Conclusion

Efforts to build back better with stronger infrastructure and technology, enhancing resilience and environmental quality will lead to a double bonus of reducing risks and revitalizing the villages, towns and cities [29]. A sustainable reconstruction approach that can conserve our resources for future generations is what is needed after a disaster. An immediate reconstruction after a disaster generally leads to a recreation of existing vulnerabilities and similar losses in future. Hence, long term policies for enhancing sustainability and resilience need to be incorporated in post disaster planning. To cite examples- In Nepal after 2015 earthquake, previous crops were replaced with a mix of Cardamom and Alder that helped to stabilize soil, increase biodiversity and reduce the risk of landslides. After 2009 earthquake, Italy decided to construct eco villages [30]. Hence the aim should be to create resilient cities and towns actively participating in promoting urban resilience policies. A resilient city is one that is dynamic, adaptive, transforming, always interacting with nature and addressing quality of life through better and greener urban planning [20]. Therefore, resilience is a process of maintaining an acceptable equilibrium in spite of continuously changing environment which needs continuous improvement and effort.

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Safeguard and Preventive Measures of Natural Disasters Using Early Warning Systems—A Comprehensive Review

S. Arvindan and D. S. Vijayan

Abstract A natural disaster is a progression of connected or unconnected events in nature that generates collapse, eradication, and losses of livelihood, life, property, and many more with extreme destruction, which is not caused or controlled by humans. Natural disasters affect natural resources and human-made property; therefore, to minimize the losses caused by natural disasters to save property, resources, and life. Addressing these problems becomes essential; hence, disaster management decides to adopt early warning system (EWS) to anticipate disaster to evacuating, safeguarding, and preventing humans as soon as possible. This paper presents the role of early warning systems in major natural disasters such as earthquakes, tsunamis, landslides, volcanos, wildfires, and epidemics. EWS attempts to reduce the risk of disasters by providing adequate and timely information by adopting numerous processes and tools to produce warning data through technical monitoring. Consequently, it generates awareness among the public for forecasting and predicting disaster, together with it has potentiality and reliability to operate 24 h a day. In the present day, many countries remarkably minimize the number of deaths by adopting EWS, but preventing infrastructure is still questionable for sudden disaster; however, moderate outbreak disasters can contribute considerable time to build up barriers and retrofitting buildings. EWS does not deliver satisfactory outcomes unless early action and communication are performed flawlessly; furthermore, warnings are still not efficiently communicated in developing countries and some developed countries due to not being technically vital in understanding the nature, locations, and frequencies. This proposed article provides detailed insight into the natural disasters using EWS for all major disasters and its evolution. Progress on the various aspects of EWS and its operation is reviewed in detail along with future scope and recommendations.

Keywords Early warning system · Natural disaster · Earthquakes · Volcano · Landslides · Epidemic

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1 Introduction

In order to avoid disasters and alert the early warning system (EWS), it is very critical before taking appropriate precautions. Improving EWS would boost the ability of all related national entities to provide prompt and successful early warnings. These projects are designed to help minimize risks, strengthen protection, and raise consciousness in regions that are vulnerable to disasters and climate change. Providing and improving monitoring equipment, building capacity, and training in the way weather stations are maintained and data collected would enable communities to become more resilient. Mao et al. demonstrated an iBMW, integrated biosensor system with mobile health and wasted water-based epidemiology to monitor the feasibility of the widespread COVID-19 worldwide. This system also helps prevent the rapid intervention and diagnosis concerning the other technologies with point-of-care biosensors' help. The POC biosensors respond to the information everywhere so quickly. Mainly, to minimize the pandemic's effect and prevent, monitor, and intervene in disaster management, the iBMW was proposed as an ideal framework [1]. Hammood et al. studied the successful utilization of flood early warning and response system (FEWRS) to prevent flood disaster's hazardous impact. The information system (IS) was conducted in FEWRS for the factors of educational quality, confirmation, perceived risks, complexity, relative advantage, user experience, compatibility, perceived ease of use, net benefits, intention to use, perceived usefulness, service quality, user satisfaction, information, and service quality in this whole study. Based on Regan and Wymer's standards, these factors were analyzed in disaster management to improve the performance of FEWRS and the utilization of the correct information technology system [2].

Zhao et al. analyzed the characteristics of different earthquake antecedents and the advantages of satellite remote sensing mechanisms for earthquake prediction. The data collected from the diversity of earthquake antecedent signals, the hypocenter's unobservability, and the features of the complexity were discussed. Four kinds of remote sensing technologies were adopted for these bottleneck processes, such as; gravity remote sensing, earth deformation remote sensing, electromagnetic remote sensing, and thermal infrared remote sensing to resolve them by reducing the risk of earthquakes in advance [3]. Li et al. presented that the initiate asperity theory from seismology enhances the embodiment level of landslide injury. The injury management interface is evenly spaced between four pore water pressure sensors and four soil pressure sensors. The results of the screening show that the sliding interface has asperity competency, and the landslide error is a movement process nonlinear. In order to do this, we are building the corresponding monitoring sensors on the surface area. An early warning method of terrestrial disasters was used for asperity theory. In future, this would boost incarnation and monitoring [4].

Fakhruddin et al. presented that the work discusses the value of danger communication as a critical component of early alerting and explores the same challenges that vulnerable communities face. The too sophisticated forecasting models and emerging early alerting methods that can be rendered in impactive is not communicated clearly. These challenges are used to fast onset dangers such as tsunamis and cyclones and slow down onset dangers such as the present COVID-19 pandemic [5]. Nury Morales-Simfors et al. studied that the critical reviews stride in random-based operations from the year 2000 onward and index anomalous random variations found in groundwater and soils. Many precursors have been remarked before the temblor or volcanic incident. Thus, no precursor can be applied for forecasting, yet retrace due to netting various complex overlapping and interacting chemical and physical methods. A dense network would require potentially viable quick and precise measurements of random over huge regions, resulting in underline valuable and episodic statistical data [6].

2 Floods

The most common form of natural disaster is the flooding, occurring when an overflow of water is overwhelmingly dry. Heavy rainfall, quick snowmelt, or a tropical cyclone or tsunami in coastal areas also cause flooding. Perera et al. studied the flood early warning system (FEWS) involving warning community and communication response capabilities. With these public collaborations, the financial and technical restraints were discussed under disaster risk reduction (DRR) policies at all levels of FEWS. Moreover, civil society organizations (CSOs) were adopted to respond positively to provide the solution for community concerns at local level challenges and to boost resilience to disaster, campaigns were held for DRR awareness at local areas [7]. Almoradie et al. explained the advantages of flood risk management (FRM) at Ghana in West Africa and found the recent gaps in developing resilience. For this opportunity of development based on the response of 53 commodities, an online investigation was conducted as the FRM in Ghana includes various pressures, drivers, and actors and multifaceted. The main focus of FEWS is to improve public awareness and the willingness of civilians and stakeholders to co-operate with FRM. From the above observation, it is concluded that the FRM is reactive rather than preventive, and the researched actors perceive FRM, interviewed stakeholders were different in contrasting approach of the success of Ghana's FRM [8].

Eibl et al. demonstrated the advanced early warning system in Iceland's subglacial flood area. The seismic ground vibration (SGV) data, GPS data, and unusual multidisciplinary hydrological data were analyzed to tracing the subglacial flood front. Before entering the river, the flood's size and time were achieved for small and large floods. For the small flood, the accretion time is 1.3 years and peak discharge = 210 ~ 380 m^3/s, and for the large flood, the time is 5.25 years, and peak discharge is more fabulous than 3000 m^3/s approximately [9]. Hussain et al. narrated a statement on the farmers' livelihoods during the natural disaster. Due to a lack of accurate information, the extreme weather changes affected farmers economically and financially as they adopted coping techniques in Multan, Punjab. By diversification of

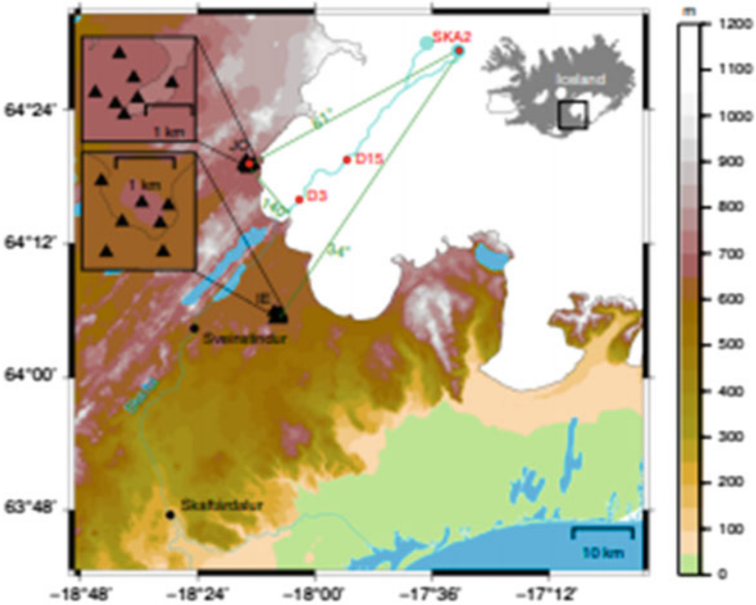

Fig. 1 Multidisciplinary flood monitoring [11]

their income and adopting sustainable natural resource conservation and management programs, the risk of daily living can be reduced. To make the farmers more capable of coping with the weather shock, some skill improvement events need to be made, and advanced early warning systems with lower access technology and information to spread public awareness. Also, some cash support like small exchangeable loans and money transfers can help them so far [10]. Figure 1 depicts monitoring of flood by adopting multidisciplinary techniques.

Chang et al. developed an advanced self-organized map that can trace typhoons up to two days earlier in Taiwan for flood prognosticates. In this study, the machine learning procedure may develop the flood early warning system (FEWS) for reservoir and risk management. This method was used to track typhoons by using flood hydrographs and the used modeling-induced predicting flood hydrographs, clustering vectors, and identifying typhoon track vectors [12].

3 Earthquake

Earthquake can be described as earthquake, induced by waves moving down and down the surface of the earth that cause: vibration of the region, vibration of tremors, license, slides, post-shocks, and/or tsunamis. The time and severity of the aftershocks are aggravating factors. Tomofumi et al. revealed the effectiveness of various kinds of succeeding generation downward forced gradiometers to detect the earthquake earlier through simulations. Based on seismic waves, both the small (*Mw* 7) and large (*Mw* > 8) earthquakes were estimated according to their magnitude, and the small earthquake was proposed as more effective in induced gravity signals of earthquake early warning systems (EEWSs). With the help of signal-to-noise ratio (SNR) value and earthquake detector and focal mechanism, the occurrence of earthquake epicenter about 140 km in the distance can be detected within 10 s [13]. Julia et al. investigated Aotearoa New Zealand citizens' survey to find out the public response to the utilization of the earthquake early warning (EEW) system. The EEW system was considered positively through people's anticipated actions during the earthquake. The public acceptance of EEW will help the future better by the more comfortable and quicker action taken within a short period (<10 s) to prevent an earthquake [14].

Francesco et al. estimated an uncertain kernel-based density calculator to evaluate the location density with given time individually with smartphone applications. The maximum high spatio-temporal intention location data collected from the advanced phones with GPS were estimated for worldwide early warning systems in time. The ungenerous is more acceptable to model location data collected by using social networks [11]. Masaru et al. insisted on the tsunami scenarios of megathrust earthquakes. Based on slip probability density function (SPDF), the framework of earthquakes for anticipated future *Mw* 8.2 Tonankai earthquake in Japan was estimated. The predicted and peak tsunami entrant time and amplitude were computed for both uniform and heterogeneous slip distribution in tsunami disaster assuagement from the estimation [15]. Figure 2 shows initial prediction of Tsunami using advanced technologies.

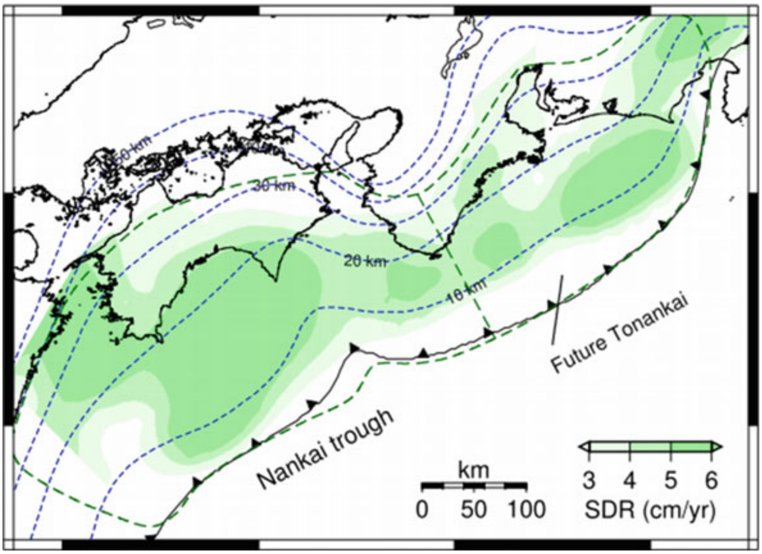

Fig. 2 Prediction of Tsunami occurs due to earthquake [16]

Yuan et al. reported an estimation about the entrance of the evolutionary enormousness for EEWS in the Sichuan-Yunnan zone in China. In this analysis, 273 programs have estimated the magnitude with τcand Pd (early warning parameters) along with P-wave time windows (PTW), where the combination of Pd and τc was considered to confirm the exact estimation for low-magnitude programs with vigorous magnitudes estimated for large earthquakes. Moreover, from the Ms 8.0 Wenchuan earthquake, the collected data's effectiveness during 2016–2017 enhanced the upcoming execution of the EEWS in the seismically vulnerable zones in China [17].

4 Landslides

Landslides can be triggered in pistes already on the rim of runoff, snowmelt, water level changes, water erosion, ground water changes, earthquakes, volcanic activity, or some combination thereof. Roberto studied a new methodology for defining the rainfall threshold for perfunctory landslides. A physically rooted transient rainfall infiltration and grid-based regional slope-stability (TRIGRS) model was applied for multiple computations of safety factors using various rainfall events. This technique could increase the effectiveness of the present LEWS, which could allow the analyses of specific areas of interest due to high susceptibility to shallow early warnings [18]. In the hilly area of the Sichuan Diocese, Zhihen et al. conveyed the data from the thorough discovery of landslides and plumes. The research analyzed the impacts on the occurrence of landslides of both rainfall and environmental factors. A landslide susceptibility index was measured using a multi-component perceptron model to express environmental factors in order to return the local landslide sensitivity. There is a probability model that combines the vulnerability and rainfall index for landslides. A logistic regression dissection was used to quantify the terrestrial threat. The conclusions indicate that it is necessary to incorporate the susceptibility index and precipitation system to improve the timeliness and precision of local early warning slides [19]. The movement of the soil using InSAR technology in landslides in Fig. 3.

Luca et al. presented the work that designates a new user-friendly tool to apply the EDuMaP process. For the "SMART" alarm model operating in the Piemonte region of Italy, the EDuMaP tool was applied. There are also significant problems and optimistic issues in the juxtaposition between the outputs of shallow landslides movement announced in rainfall thresholds (SMART) with other models that are used in different Te-LEWS. The results showed that the above approach could lead to an inaccurate and unprofessional assessment of the warning model [16]. Johannes et al. (2020) suggested the analysis of the upcoming big miscarriage of the rock slope at the Hochvogel summit. A measurement tape extensometer indicates a 35 cm opening of a central seam, with mean campaign speeds of 9.6 mm/month between 2014 and 2020. A high-resolution crack-opening and rain data automated geotechnical operating process is in operation from 2018 [20].

Chun et al. reported that the united multi-temporal landslide inventories in logistic return patterns could be seen as the embodiment of rainfall that triggered landslide

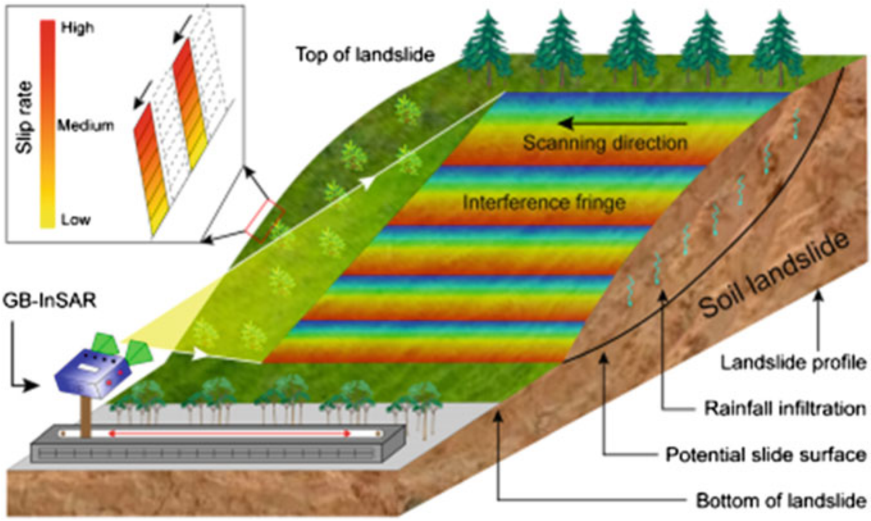

Fig. 3 Anticipation of soil movement using ground-based InSAR [4]

danger beneath weather change. A technology called quantitative precipitation estimation and segregation using multiple sensors (QPESUMS) was adopted to gain a spatio-temporal rainfall model and help prevent hill slope disasters beneath weather change. The overall outcomes show that the calibrated model 2005 is elevated in the general period with the precision of 78%; for highly rainfall typhoons, the calibrated pattern of 2009 would perform excellently (72%) [21].

5 Tsunami

A tsunami is a massive wave of devastation that is possible due to any disruption that quickly displaces a large mass of water triggered by an earthquake, volcanic eruption, or the impact of a meteorite. However, an undersea earthquake is the most common cause. Alexa et al. said that the study showed that there is a significant shift in convictions when it comes to an immediate evacuation and tsunami. It is over-sized for those in the flooded region in contrast to those outside the hazardous zone, despite the sense of tension associated with potential evacuations. These findings increase anxiety, given the importance for those confronted with difficulties for personal and evacuation intentions. Our findings show how different perceptions from the same perception of danger impact: urgencies and future plans for evacuation in different ways [22]. The magnitude Mw 7.8 Palu, Indonesia temblor occurred on September 28, 2018 at 10:02 UTC, Jann-Yenq et al. There, the tsunami moving ionospheric disturbances are observed by records of the five terrestrial worldwide satellite navigation systems (GNSS) reception systems (TTIDS). A total of 15 TTIDS

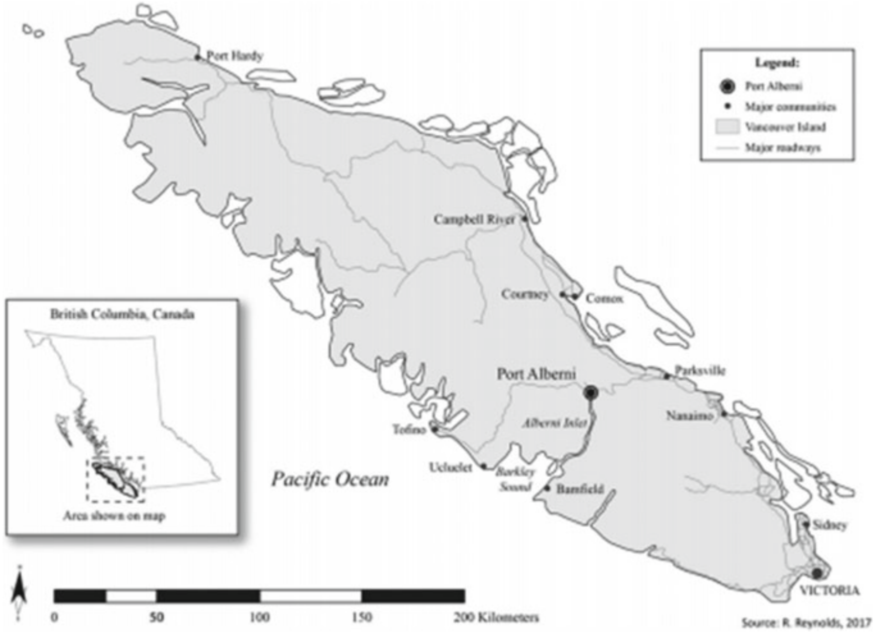

Fig. 4 Tsunami prediction in Vancouver Island [25]

were found. The tsunami source place, rooted in the results of both techniques, also includes a bootstrap method. They have also used the method of monitoring the tsunamis in order to assess the possible sites in Palu Bay. They identify coastal landslides through video study, field survey, and satellite images [23].

Sofyan et al. presented that the researchers examined how Acens disaster management and preparedness have developed since the 2004 center point of its early warning system (EWS), and especially, how the timely united EWS approach has been incorporated into its evolution and monitoring. Much research is made where the findings recommend that a multi-hazard EWS is not well-evolved, and a linear EWS pattern is imminent. The adequate instructions are made to review policy and practice for Aceh governments at territorial and district levels and other stakeholders to enhance the present EWS [24]. Figure 4 depicts map of Vancouver Island to predict Tsunami.

6 Volcano

Volcanic eruptions are general exits of hot magma (lava) or earthen materials, which form high pressure and temperature flight from the mantle through various crustacean defaults or vents. Often the magma gets its way out of the mantle due to intense pressure and heat. The tectonic movement or movement of the different layers of the crust can also cause the volcanic eruption. Aloisi et al. proposed a combining systematic and FEM modeling of all achievable continuous deformation data, centering on signals over 24–25 December when continuous distortion networks recorded clean variations straightly related to the dyke ascent. There is also a high-price GPS enabled soon and reliable source model. There are borehole types of equipment starting one hour before those recorded by GPS and mainly made it able to enhance the dyke ascent modeling [26]. Asyik et al. presented the application operating for active volcanoes applying wireless sensor network (WSN) and Internet Of Things (IoT). Our primary purpose was to generate low-energy consumption resilient, integrated, dolly to deploy, and power saving. Indonesia hosts 127 active monitorable for the activity around the clock. It shows that the higher the number of monitoring points, the more costly it will be to earn the equipment needed for the volcano monitoring. Thus, it needs monitoring devices that are dominant and efficient [27].

Chu et al. have expressed the evolution of the latest volcanic hot spots automated detection algorithm (FYVOLC) using new-generation Chinese satellite FY-4A data. By adding a regular brightness temperature difference index (NbIDI), FYVOLC improves the sensing capability of the volcanic anomaly program (VAST) algorithm to lower the impact of cold cloud. The FYVOLC algorithm is stable with more accurate detection and less inaccurate or false detection betide. The FYVOLC overall wrong rate was 12%; the 11% misstate the right rate was 89–97%. The variations of thermal anomaly can also be introduced by FYVOLC during time [25]. The entire volcanic eruption phase in Mount Etna is shown in Fig. 5.

Giudicepietro et al. submitted the main volcanic crisis in Stromboli in the last decades and its implications for hazards and injuries during the eruptive stage of

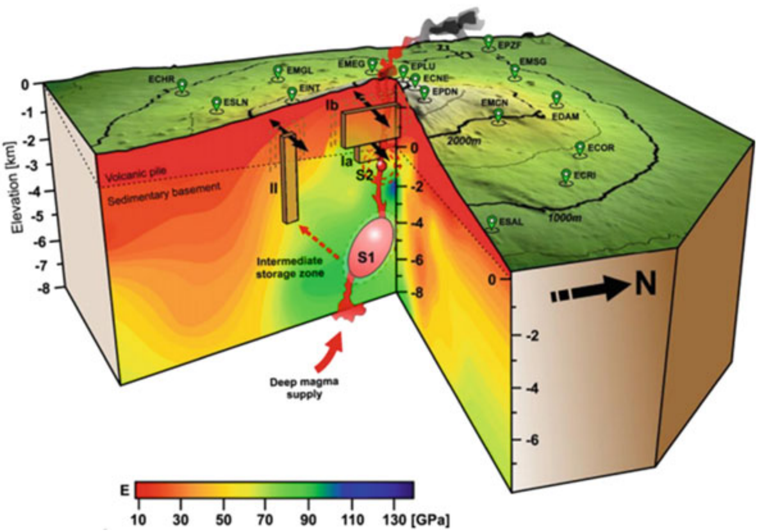

Fig. 5 Process of volcanic eruption in mount etna [28]

July–August 2019. More precisely, before the start of the eruptive crisis in July–August 2019 there were no remarkable changes in seismic amplitude. However, the VLP (several long period) and VLP amplitudes increased sharply between about a month before the height of July 3. These changes suggest higher gas content in the explosive activity of Stromboli. Our study recommended that gas be a big part of the eruptive dynamics of Stromboli and that two kinds of magmas, LP, and HP magma co-exist. These parameters could mitigate the effects on the island of potential violent explosion [29].

Mereu et al. studied the relevance for the competence of paroxysmal operation in Etna of the combined use of the TIR camera, the polarimetric X-band, and the Doppler L-band radars. In 2013 and 2015, current dissection 5 Etna eruptions took place. We implemented a retrieval algorithm for the Jet Areas (JR3A) rooted in a verdict tree combining the observable polarimetric X-band with the impaction of 1band radar, aiming at exantheme IJR height detection. In an early warning system, it offers information of all climatique conditions and the advantage of using a polarimetric X-band climate radar. We also show that JR3A can also be collected in unclean environments if data cannot be processed by the thermal infrared (TIR) camera [30].

7 Future Scope and Recommendation

Future scope and recommendation of the EWS will improve the broad research areas and efficiency in this system very effectively. Some of the predicted progress and recommendations are given below.

- EWS can be used as a monitoring system continuously from the beginning till the end for both short and long-term
- Future of EWS requires a greater understanding of technical gadgets used for applications like signal processing, instrumentation, and mathematical techniques to predict natural disasters or any unusual events
- The future approach toward EWS should consider cost consumptions to apply this technique even in remote areas
- EWS systems should be designed to favorable for all environmental conditions to predict the event more accurately
- Advanced technology should be adopted to predict natural disasters with higher efficiency and lower cost

8 Conclusion

The current paper has presented a critical review of methodologies applied to enhance the early warning systems for natural disasters to alert people before the event. Best practices strategies were discussed to improve the early warning systems provided by crucial guideline refine from the literature. Key findings from this review article are outlined below.

- The most comprehensive studies provided in this analysis with detailed operational evaluation and monitoring systems all-inclusive before and after disasters events
- The review has focused on a wide range of approaches being applied in the literature when undertaking operational evaluation
- The approaches applied in each case study were influenced by the pivotal performance of early warning systems for major natural disasters such as earthquake, volcano, landslides, tsunami, epidemic, and extreme flooding
- The early warning system is based on the decision-making process with monitoring data and previous experience.
- Discussion on various advanced early warning systems to predict natural disasters as early as possible to take precautions

Application of early warning systems has been discussed in detail with the help of previous works reported.

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Potentiality Assessment of Community Open Space for Disaster Management Purpose: A Participatory Approach to Reduce Disaster Vulnerability on a Community

Sharmin Akter, Most. Asma Khatun, Tanmoy Dev, Nazia Hossain, and Dulal Sarker

Abstract Urban open spaces can be defined as one of the most critical component of city design that provides recreational, social, and other facilities to the city dwellers. Besides, these places have a great influence on repairing climate change impact and solving other environmental issues. Nevertheless, the concept of integrating the planning and management strategies of urban open spaces with disaster management strategy development remains unanticipated in the context of urban planning. In this study, the concept of the community participated disaster vulnerability reduction has been applied to identify associated risk, capacity, and potentiality of using open spaces for disaster management purposes. At every step, various types of participatory planning tools were used to identify the best reliable options. In the first step, the community assessed and identified associated risks regarding existing open space and waterbody preservation and use. Community people identified rapid urbanization as the major cause of open space and waterbody reduction. In the second phase, community capacity in terms of institutional organization and community resources was identified. At the final stage, opinion from community people, interview of the key informant, and expert opinion survey helped a lot to identify the potentiality of open spaces and water bodies for disaster management purposes. Community developed strategies and different types of proposals from community peoples and experts have also proposed to identify the ultimate potentiality. Although this study was conducted only for a specific community, the method can be applied to identify all of the aspects of disaster management for other communities as well.

Keywords Community open space · Water bodies · Community participation · Disaster management · Participatory vulnerability reduction (PVR)

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1 Background of the study

Social spaces are the mirror of society [17]. Open space in urban areas is an urban space that is open and accessible in nature. Accessibility system is open for people of all ages, gender, classes, ethics or socio-economic level. As like, Parks and Open Green grounds are open and accessible in nature. And these open spaces are successful only when these places become able to meet the recreational, social and psychological needs of the space users as well as the city dwellers [3, 5]. Apart from fulfilling social, recreational and psychological needs of the city dwellers, spatial planning and modelling of open spaces also aims of maintaining the environmental quality of the city. But, decreasing number of open spaces at urban areas creates a threat towards maintaining the environmental and social quality of the city [1]. According to the updated master plan of Rajshahi city at 2008 by Rajshahi Development Authority (RDA), the identified number of open spaces were 95 with the area of 125.37 acres. But in recent time, through ground-truthing of the identified places, presence of only 65 open spaces were confirmed with the area of 89.73 acres [15]. Not only the reduction but also less use and not used at all is one of the major problems in most of the urban open spaces. But in case of making cities more resilient and sustainable, increasing recognition, use and development of urban open spaces is must require [7]. Beyond the use of the open spaces for recreational purpose, effective management and implication of these open places can also have a great impact to make the city more resilient [10]. But, lack of proper and planned consideration such an important resource of our city is losing its significance day by day. Plans regarding using urban open spaces as a strategy for disaster resilient city development will be more effective if the community people can be incorporated in the planning process. So, this study aims to analyze existing using scenarios of the open spaces and to provide some community-based solutions for effective management of existing open spaces as well as using these places at the time of natural disaster (fire hazard, waterlogging).

2 Literature Review

2.1 Concept of Community Open Spaces and Their Importance

A smart urban management can fulfill the goal of making city more resilient that can also be termed as qualitative urban planning. Effective and sufficient number of open spaces at the city area provides the benefits of improving urban performance in case of normal situation or at the eve of any disaster situation [9]. Community open spaces provide space for community gathering, for relaxation and for different types of cultural and physical activities. Mostly, it plays vital role in social interaction and influences people's behavior [9, 16]. Green open spaces play vital role for physical activities of city dwellers and are potential to reduce stress as well as mental health improvement of them [4]. In most of the cases, open spaces at city area act as a space to celebrate diversified activities, a place to meet strangers, to spend a quality time at natural environment [21]. Recreational use of public open spaces added huge economic benefit to city's development. Presence of natural, architectural, cultural and recreational elements at public places increase property value as well as revenue of municipalities [8]. Small food carts, street hops are common in urban open spaces and parks which adds an economic value to these spaces.

2.2 Using Open Spaces as a Tool for Disaster Management

Potentiality of using open spaces can be integrated at three main aspects of disaster management. These are emergency response phase, recovery phase, and mitigation strategy development. At present, planning and designing consideration of open spaces mainly focuses on social issues. After that economic and environmental issue comes. All of three items are mainly the pillars of sustainability. And sustainable development always includes the issues of disaster resilience at the city design and development manual. so, at the time of planning and design consideration of open spaces these issues must be considered [14]. Due to rapid growth, urbanization, encroachment of open lands, green coverage of the city reduced and impermeable surface increases. Thus, water holding capacity of ground surface has decreased much [11]. In different case studies of flood occurrences in US, concluded that maintaining the wetlands was far cheaper option to reduce flood occurrences than building any kind of Dam or dykes. The case study of San Francisco earthquake (1906) was examined through morphological analysis and found a relationship between city's-built form and open spaces at the time of earthquake and subsequent fire. Open spaces during that time were transformed into shelter for survivors [2]. In order to mitigate disaster such as, fire hazards, earthquake, major role played by the open space network is to rescue the victims to safer place. Regulations of National Disaster Management Agency No 11/2008 states that high accessibility at the households and adequate number of open spaces are most important for post disaster recovery activities. Network of open space also identified as a most effective tool for rescuing in a short time and also evacuation of victims [18].

2.3 Community-Based Approaches for Disaster Management

Community-based disaster management (CBDM) approach for disaster management mainly helps to increase the community capacity for assessing the community vulnerability against any natural and human-made disaster. In this process, community peoples are always encouraged to work together accepting the ownership to reduce the disaster vulnerability and also develops strategies to reduce the risks at multiple levels [13]. CBDM aims to reduce vulnerabilities, increasing capacities, prevent or minimizing the loss and damage of life, environment, minimizing human suffering, and hasten recovery [6, 13] Apart from these, in case of disaster management from prevention, mitigation, response, relief, and recovery, community is the first level responder [19]. So, active community participation and CBDM is the most needed to achieve sustainability in dealing with the risks of any disasters [12]. In recent times, studies have been carried out to integrate public participation to reduce the disaster vulnerability and to increase the community capacity. Among all of the relevant studies the concept of Participatory Vulnerability Reduction (PVR) incorporating the concept of CBDM was introduced by some researchers. The main concept of PVR stands to assess community vulnerability, capacity, and strategies developed by the community that considers community capacity and resources. The framework of PVR includes 3 basic things. These are vulnerability assessment, capacity assessment and community Action [20]. According to them, PVR more specifically includes the following things,

1. *Vulnerability assessment:* Identifying vulnerable groups, location and root causes of vulnerability.
2. *Capacity assessment:* Identifying community resource, organizational structure, and institutional context.
3. *Community Action:* Developing community-based plan to overcome root causes and developing community leading organizational setup for coordinated actions.

3 Methodology

3.1 Study Area Profile

Among 30 wards of Rajshahi City Corporation, Ward-25 has been selected for conducting the study. The study area has a close proximity at the north bank of the mighty river "the Padma" with two localities named Talaimari and Raninagar. Previously a high volume of open spaces was present at the RCC area. According to the master plan of 2008, total area of open spaces were 125.37 acres. But recently, the area decreases at 89.73 acres [15]. According to the study Ward-25, ward-26, ward-28 have been identified as most vulnerable for open space reduction. After selecting these places, a systematic field reconnaissance survey along with consulting with ward councilor has been conducted where Ward-25 has been identified according to the study potentiality (Fig. 1).

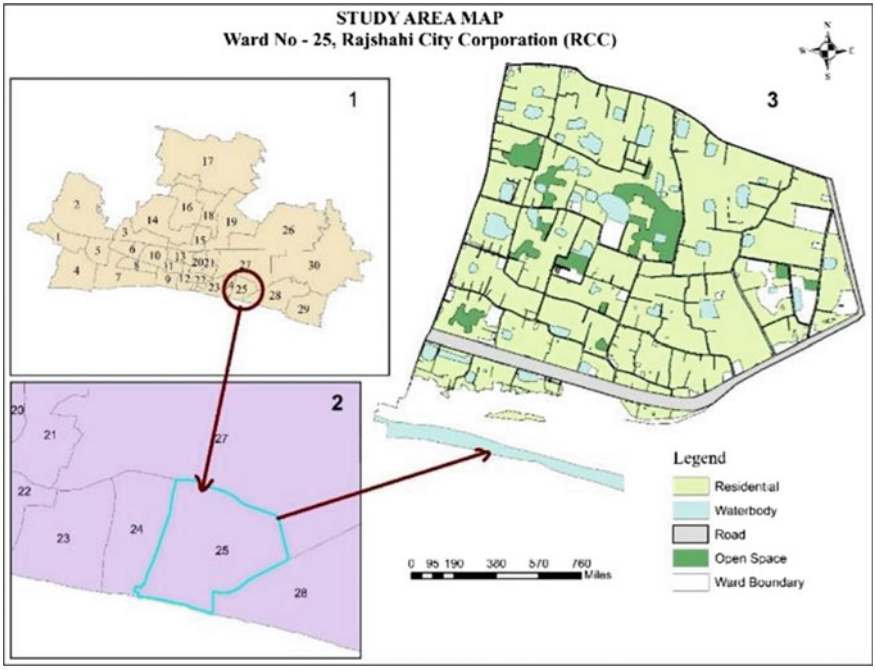

Fig. 1 Location and Land use of the study area

3.2 Implication of PVR Technique

The method of participatory vulnerability reduction (PVR) was used in this study through using different types of tools of Participatory Urban Appraisal (PUR). As the study is about disaster management strategy development so the whole study has been divided into three aspects. The 3 aspects are 1. Disaster risk assessment 2. Capacity assessment 3. Potentiality assessment. In each step of the study, different types of participatory tools were implied. Different types of tools used and expected outcome of the tools has given below (Table 1).

4 Results and Discussion

This section mainly describes the tools used at different phases of the study and explains the results generated from the study integrating with the current situation of the study area.

Table 1 Implication of participatory tools

Aspects	Tool used	Expected outcome
Disaster risk assessment	Social map	Existing socio-physical condition of the selected area
	Timeline analysis	Historical background of open space and waterbody reduction
	Cause effect diagram	Analyzing major problems, causes and the consequences towards the open space and waterbody reduction in the study area
	Pairwise ranking	Ranking of problems and identifying root causes of the risk
Capacity assessment	Resource map	Identifying resource availability at the community
	Mobility map	Extent of influence area, transport use, visits in group or singly, etc
	Venn diagram	Understanding organizational structure and collaboration
	Key informant	Existing management system of open space and water bodies
	Focus group discussion (FGD)	Analyzing community human resource availability,
Potentiality assessment	SWOT analysis	Identifying community strength and opportunities considering weakness and threats
	Focus group discussion (FGD)	Community willingness regarding open space use and developing community-based organizational setup for further actions
	Key informant interview	Potentiality of using community open spaces at local context
	Expert opinion	Existing plan for the space, potentiality towards using area for disaster management

4.1 Vulnerability Assessment

To assess the existing disaster vulnerability associated with the study location, 4 different participatory tools were used. These are historical timeline analysis, social map, cause-effect diagram, and pair-wise ranking matrix. Each of the tools helped to identify different types of vulnerability in the study area.

Historical Trend of Open Space and Waterbody Reduction. A comprehensive historical background of any area provides to access historical trends and patterns of any development of any area. Through analyzing the trend major problems towards any development can also be identified. The historical trend of the area of the study area has been shown in this study through a timeline series. Data for the timeline series was collected from a focus group discussion. At the time of historical trend analysis, a number of resource persons were suggested to know more about the historical trend of the area.

At the time of historical data collection through focus group discussion, questions were asked to the participants creating a landmark on historical events. Different types of problems specific questions were also asked to know the source and root time of the problem started (Table 2).

Historical trend of the community shows that after the establishment of city administrative authorities, more focus was given on the development of the community. The establishment of a water treatment plant, deep tube-well, and drainage system shows a planned development procedure of the study area. But the problems started after 2000. In between 1987–2011, the city corporation authority focused on developing accessibility at the whole city corporation area. And improved accessibility

Table 2 Historical trend of physical change in the community

Year	Events	Remarks
1825	Establishment of district head quarter	–
1876	Municipality establishment	–
1987	Establishment of city corporation	–
1977	Water supply connection at ward 25	–
1980	Establishment of Baitul Hamed mosque	–
1984	Water treatment plant	Developed water quality
1992	Construction of deep tube-well	Availability of drinking water
1994	Construction open drain	Drainage was developed to minimize water logging issue. But due to mismanagement and unstructured drainage outfall the problem was not completely solved
2000	High building density	Open space reduction
2002	Decrease water body	Ecological imbalance
1987-2011	Construct of road network	Increase connectivity and accessibility
2013	Gas connection and drainage facilities	Another attempt to solve the problem with water logging issue
2014	Prohibit outlet of septic tanks in open drain	–
2016	Filling the pond and construction of high-rise building	Waterbody reduction and ecological imbalance
2018	Filling the pond and construction of high-rise building in open spaces	Pond filling and open space reduction
2019	Continued construction of building	Open space reduction

Source Field survey, 2020

advanced the development to rapid infrastructural development in the study area. Rapid infrastructural development caused open space and waterbody reduction of this area. After that in 2016, trends of high-rise building development started again for the development of different types of building developer groups and the trend is still ongoing. As a result, the rapid reduction of open space and waterbody is seen in the study area. And still the process is ongoing. According to development history, the area has not experienced massive fire hazard incidents, but the community is the worst sufferer of waterlogging issues. Community peoples always face the problem of waterlogging whenever a little rainfall occurs. When the matter is about heavy rainfall the situation is as much as worse that is beyond expression. Besides, low cluster housing area and riverside slum area is more vulnerable to fire hazard due to housing conditions with narrow alloys and no wide road facilities.

Existing Social and Physical Vulnerability of the Area. Raninagar and Talaimari of the study area are mostly close to the CBD area of the Rajshahi city with greater connectivity and other facilities. All of these facilities lead to the rapid development of the study area. As almost all of the open spaces are private property, so the owners of the lands prefer to construct buildings on their own land for economic and financial benefit. A social map (Fig. 1) has been prepared to show the existing infrastructural, transportation, educational, recreational, and other facilities.

In broader classification, the area can be divided into three—1. Cluster housing area with limited or no open spaces contributing fewer potential scopes for disaster management; 2. Low-density housing area with a number of water bodies, open spaces, and potential scopes for disaster management, and 3. Riverside slum area which is more vulnerable to disaster.

Cluster Housing Area. With limited or no open spaces contributing fewer potential scopes for disaster management: houses are closely built up providing 1’-2’ gap or no space (shared wall) in between. At these locations, open spaces, water bodies, and greeneries are hardly visible in google images as well as in the field. People cannot visit open spaces for regular refreshment and children (below 10 years old) hardly access to playground or open spaces. Again, in case of heavy rain, the area is fully dependent on drainage infrastructure for storm water management resulting in water logging at many spaces (Fig. 2).

Low-density Housing Area. With a number of water bodies, open spaces, and potential scopes for disaster management: houses are closely built up with a nearby central open space (mostly private land) or water body and greeneries. The open spaces are used by children of surrounding households as playgrounds and groups of women are also found to gossip. Some spaces are restricted for the playing of children by members of surrounding households. Some spaces and low lands are used as dumping sites.

River Side Slum Area. Which is more vulnerable to disaster in river side slum areas, poor class housing builds up with much fewer spaces or no spaces in between. Open spaces are found on the riverbank side and at some locations, water bodies are also found in poor condition. From the top, a large flat structure (a no. of households and hundreds of populations) is viewed. Peoples living in the riverside slum area and Raninagar area are highly vulnerable to any fire hazard incident as the area is one of

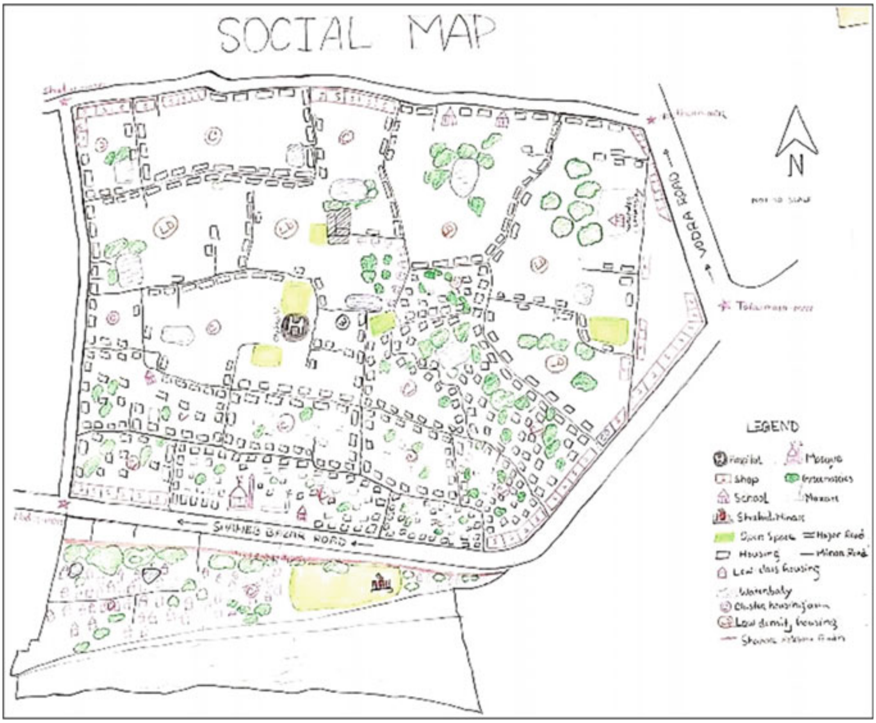

Fig. 2 Existing social condition of the study area *Source* Field Survey, 2020

the densest areas. People of these area uses a narrow alloy to reach their home. And there has no emergency lane where emergency transport can get access whenever necessary. The buildings are so close that, if any fire accident occurs it will not take much time to spread over the whole community.

Major Problems Related to the Use of Open Space and Water bodies. At present days, due to population growth and rapid urbanization, extra pressure is being created on community open spaces and water resources. As a result, the rapid reduction of open space and pond filling is a common phenomenon to meet extra infrastructural and other utility demand. In that sense, 2 most important problems related to the open space and waterbody have been identified by the community people. These are,

1. Reduction of open space and waterbody
2. Un-use and underuse of open space.
3. After identification of these two problems, the inherent causes and their effect on the community people have also been identified.

Major Causes Behind Reduction of Open Space and Waterbody and Its Effect. There is a number of causes of reduction of open spaces and water bodies of which some are more vibrant than others (Fig. 3).

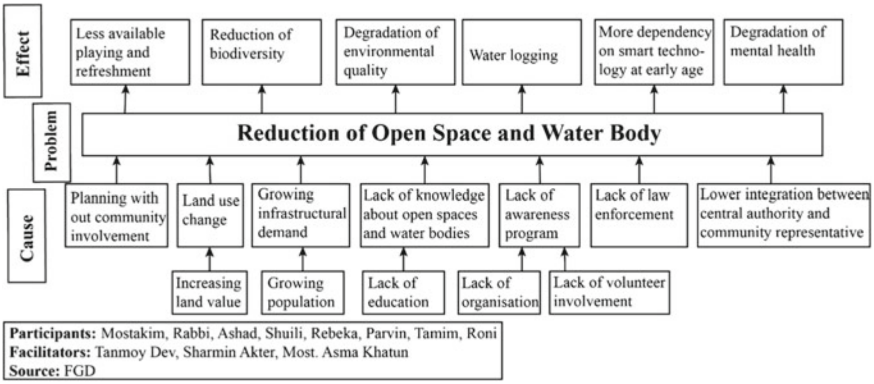

Fig. 3 Cause-effect diagram of reduction of open space and water body. *Source* Field Survey, 2020

The pair-wise ranking method is utilized to rank the causes or sub-problems and finding the most vibrant issues. In the pair-wise ranking method two problems are compared at a time and the frequency of each item preferred the comparison is ascertained which gives the idea of preference of people. Thus, the method is utilized in the study, and the 1st, 2nd, and 3rd ranked causes are extracted. These are:

1. Lower integration between central and local authorities
2. Planning without community
3. Growing demand for infrastructure

Lower integration of RCC, RDA with community representatives and local organizations (exempt Ward commissioner) plays a vital role in the reduction of open spaces and water bodies. Weak planning structure and lack of awareness of the community people regarding the benefits of open spaces and water bodies and the consequences of their reduction contributing to the problem of lower integration between central and local authorities. This in turn contributes to not taking any initiative regarding the preservation of open spaces and water bodies.

With the increase in population, the demand for infrastructure is constantly rising and it is highest in urban areas. An increase in population and an increase in land value are contributing to the increase in infrastructure demand which causes rapid infrastructural development. And it ended up filling ponds and constructing at a handful of open spaces.

"Planning without incorporating the community people" often causes great trouble. For example, there are some open spaces left with no concern, and ended up utilizing it as a dumping site. If the planning was made with community people with due concern to this issue, the scenario would be different now. Lower Providence of responsible authorities and Lack of initiative regarding long-term planning are the causes behind planning without community.

Major Causes Behind Un-use and Underuse of Open Space and Waterbody and Its Effect. Being unused and underused has been identified as the second problem regarding problems related to open space by the community people. A significant number of causes have also been identified that are responsible for this problem.

After that pair-wise ranking matrix has been created through community involvement for prioritizing the causes and to find out the most influential causes. In this respect mostly influential causes regarding open space being unused and underused are,

1. Poor management system of existing open spaces
2. Surrounding the built environment
3. Lack of proper knowledge regarding open space utilization

After that most influential causes have been identified as problems and further causes and effects have been revealed. Management issue is found one of the most important things for any site development or to determine the quality of any space. Community people argues that, poor management of the existing spaces encourage water dumping and makes places less attractive to everyday users. Besides placing construction materials for a longer time period makes places less user friendly. All of these problems lead to make places less accessible as well as less available open spaces. The major causes behind this kind of problem are a lack of awareness and cooperation among the landowner and related stakeholders (Fig. 4).

Surrounding the built environment has been identified as the second most prioritized problem for being an unused or underused condition of any space. Different types of building structures and building materials used (e.g.: glass at the window) make places more vulnerable in view of playing children around the building. So, the owners usually restrict children from playing in these areas.

In the study, a huge number of unused open spaces has been identified through field survey, but the guardians of the children are not aware of this, and they do not have any headache regarding them. Rather they allow their children to use smart

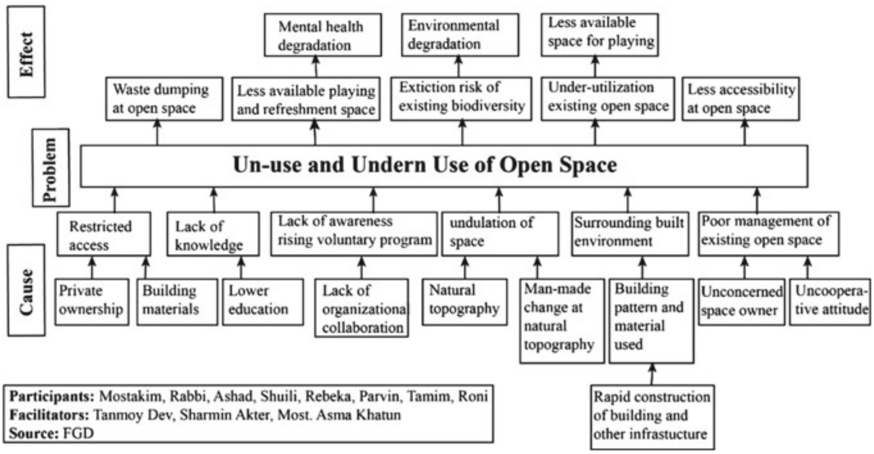

Fig. 4 Cause effect diagram of un-use and under use of open spaces. *Source* Field Survey, 2020

technology. That happens because of lack of knowledge and awareness among the community peoples.

5 Capacity of Community to Reduce the Risk on Open Space and Waterbody

5.1 Resource Availability in the Study Area

The resource map shows the existing available open spaces and the demolished open spaces as well. It also shows the open spaces that are in under demolition. The results of this mapping show the higher demolition rates of the open spaces and lower number of open spaces according to the community requirement. As the number of community open spaces is declining day by day people use small social spaces as a place of social interaction in the study area and these areas have also been identified. Although the pond filling scenario is severe in the Rajshahi city corporation area, this study area is also in a vulnerable condition. In some parts of the area, building has been constructed by filling the waterbody. This results in waterlogging, and other problems in the study area.

In the study area Hadir mor to city hospital road, Raninagar pro-poor residential area and Hadir mor to Shadhur mor road have been identified as the most vulnerable to waterlogging. But till now, the existing amount of waterbody shows higher potentiality regarding the management of waterlogging situation through incorporating the use of existing open spaces at different policy issues (Fig. 5).

5.2 Institutional Arrangement and Dependency of the Community People

Whenever we want to assess the capacity of any community for disaster management purposes community institutional and organizational capacity assessment is as much as important as national disaster management capacity assessment. So, it is important to understand the community organizations and active groups of any community. And how the groups interact with others and outsider institutions must be studied as well. This approach will help the policymakers and the plan development, executive, and management committee to identify the existing institutional gaps among different institutions and will be helpful to make the relationship stronger (Fig. 6).

Institutions Having High Influence. Ward council of the area is located near the "Talaimari Katchabazar" area. A Ward council is an organization where a group of community representatives is included along with the ward councilor. And the ward council has a great influence regarding open space management and waterbody preservation. In the study area, almost 1 acre of the land area of the ward councilor

Fig. 5 Existing community resource of the study area *Source* Field Survey, 2020

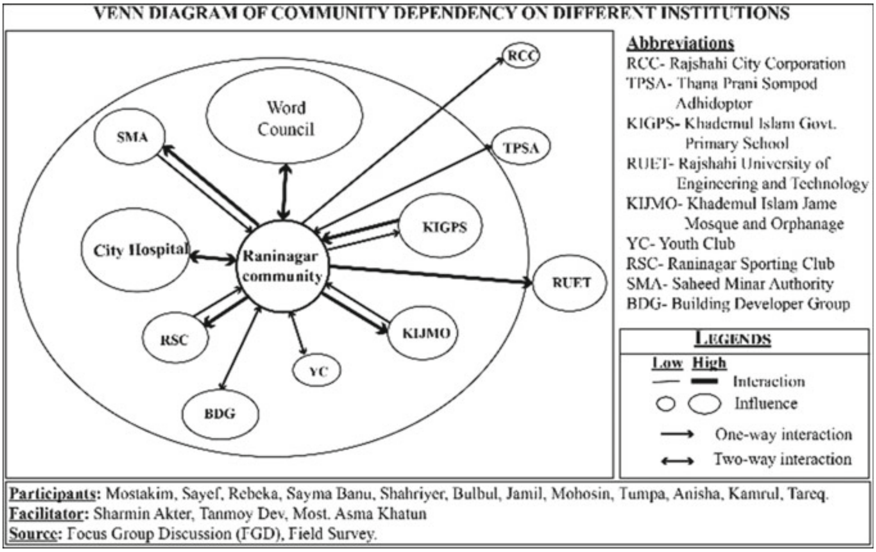

Fig. 6 Institutional dependency related to open space use. *Source* Field Survey, 2020

has been declared as open space and the waqf initiative has been taken for further preservation of the spaces. A small part of the area is using as a settlement for rootless people in a condition of not hampering any existing features of the area. In this regard, the ward councilor of the area said that,

> The designated land is our inheritance property and obviously private property. As this area is a large open area so my grandfather allowed some rootless people for living here. But some restrictions have been given on them not to hamper any trees or other features of the area. And the peoples are also living there happily.
>
> —(Key informant interview__1)

In this respect, a resident of this area named Rebeka said that,

> "I am living here since my childhood. Ward councilor has given us all types of utility facilities regarding electricity, water facilities. So, we do not have any other wanting from him and we always try to respect his words."
>
> —(Focus group discussion__1)

Apart from this RUET playground and City hospital playground is most attractive to the children group. They usually go weekly to the RUET playground and the other time they prefer City hospital or shaheed Minar playground.

Institutions having lower influence Among all the institutions Raninagar sports club, Khademul Islam govt. primary school, Khademul Islam Jame Mosque, and Orphanage have significantly lower influence. Among them Khademul Islam govt. primary school has potentiality for space use but the entry is restricted. In this respect, a student named kalam said that,

> "Khademul school is very close to my house. But I am not a student of this school and none of my friends can go there to play."
>
> —(Focus group discussion__2)

Besides Khademul mosque and orphanage do not have any significant space and Raninagar sports club uses the city hospital playground for annual sports competition. Beyond this, the orphan children and club members use the city hospital field and shaheed Minar for daily playing or other activities.

5.3 Mobility Pattern of Community People Regarding Open Space Use

A mobility map generally explores the mobility pattern of the community people. It shows the movement pattern of an individual, a group, or the community. Major focus is given on where, how and for what people go to the significant places. It reflects the people's perception of movement patterns and the reasons thereof.

From the study, it is found that only children below 18, women visit open spaces for the purpose of playing and refreshment. A mobility map is used here to explore their movement pattern to the open spaces. Children regularly visit there nearby

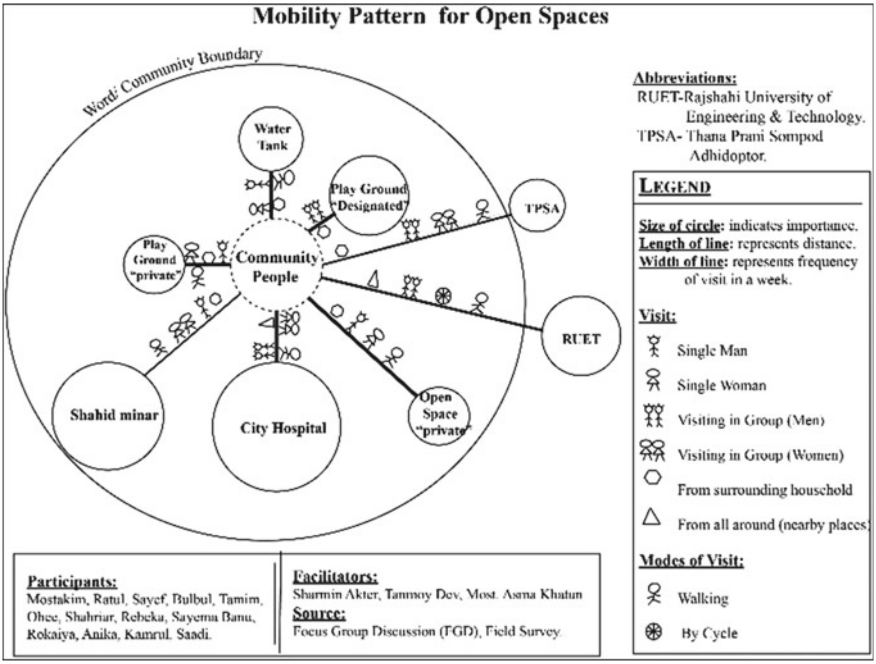

Fig. 7 Community mobility pattern regarding open space use. *Source* Field Survey, 2020

small open spaces (mostly private lands, not designated playground) in a group or singly for playing. There is socially designated two playgrounds (Shahid Minar-field, playground of city hospital) fall within the ward boundary and one (RUET playground) outside the boundary. More specifically, the playground of city hospital being in the central zone serves the whole ward. On weekends, children used to visit in groups either RUET playground or Shahid Minar-field (Fig. 7).

6 Potentiality of the Open Spaces and Water Bodies Towards Disaster Management Strategy Development

6.1 Insight of Community People Regarding Using the Open Spaces for Disaster Management

In the case of community-based disaster management strategy development, the insight of the community people is the most important thing. To find out the potentiality of community open space and water bodies for disaster management purpose, both positive and negative response were assembled. One of the residents of that area named Aminul Huq said that,

> We are suffering from waterlogging area for a long time, the whole golley (narrow pathway) of this area sink with water whenever it rains. Sometimes if heavy rainfall occurs water level raise so high that it comes up at our front yard. And the wastes of drainage always mix with the rainwater that is very much irritating. If the problem can be solved with proper management of open space and water bodies, it will be really good for us. We all will cooperate with the authority and we all will help according to our capacity.
>
> —(Focus group discussion__3)

But the problem occurred with some of the owners of the vacant land. According to one of the owners,

> This vacant land is my private property. As I have my own house now, the area is vacant and the children always play there. But in the future, my children's will make their house for themselves in this land. And the disaster problem is the problem of the whole community. So, everyone should contribute to their land.
>
> —(Focus group discussion__3)

After taking the insights and the problems of community people in consideration, these issues were discussed with Mr. Tariqul Islam Paltu, who is the honorable councilor of Ward-25. He is also a key informant of this study. After hearing the insights and comments from the community people he shared his insight regarding the potentiality of open space and waterbody use for disaster management purposes.

Key Informant Name: Md. Tarikul Islam Paltu
Designation: Councilor, Ward No-25, Rajshahi City Corporation (RCC)
In case of space potentiality, he says, "*Our ward area is blessed with a large number of water bodies and greeneries. But after 2016, the amount suddenly started to decrease at a rapid rate. These two factors work that is rapid urbanization and lack of awareness. We cannot stop the urbanization, but we can increase the awareness level easily. We all know the general importance of open space and water bodies, but addressing the potentiality of these issues for disaster management purposes is really new for us. I think if we can form a committee in this respect that will be much effective. But unfortunately, we do not have any committee in this regard. Besides, if we can involve school college-going children's, that can carry a good fortune. In that case, school-level committee formation can be more effective.*"

6.2 Insights of Experts Regarding the Use and Potentiality of Open Spaces and Water Bodies

Experts have shared their views regarding the use and potentiality of community open spaces and water bodies. Their insights regarding this issue addressed core problems lies within organizations and human behavior and also opened up so many scopes and potentialities of the area. Experts have presented their valuable insights according to their area of expertise. Their opinions are presented below:

Debasis Chacrabarty emphasized more on the bottom-up planning approach in order to the successfulness of plans and proposals regarding the conservation of open spaces and water bodies as well as to address community problems and proper utilization of the spaces.

Expert Name: Debasis Chacrabarty,
Designation: Land use expert, Rajshahi Development Authority (RDA), Rajshahi
"All of the community open spaces are private property, but, while the issue is about planning, these places are considered as open spaces. Being private property government cannot rule over the community spaces. Moreover, mismatching in existing land-use and land-use at mouza, less consideration towards community open spaces, no control over pond filling cause decrease in open spaces & pond filling".
He also discussed about the presented project that RDA and RCC going through. He says,
"At recent times, according to the ongoing master plan, a strong barrier will be created on the case of pond filling and will also re-excavate clogged water bodies. In this case, unused and clogged waterbody (locally known as Doba) will give equal importance. If at any purpose, pond filling is must be needed, they have to submit a particular fee to RDA. In this way, waterlogging issues will be reduced to some extent".
"The problem of waterlogging is mainly due to the dead-end drainage structure and no existence of outfall of drainage. Drainage outfall has to be well structured and some of the water bodies can be these outfalls".

Another expert of his study, Md. Fakrul Alam has emphasized on community organization who will address community need to higher authority through maintaining a proper channel and also focused on the transparency and accountability within the organization. She also accuses the poor drainage condition of massive waterlogging issues.

Expert Name: Md. Fakhrul Alam
Designation: Planner, Urban Development Directorate (UDD)
"To use open space for a particular use, especially, for disaster management, it requires to know the size of the space available. The case is the same for water bodies. Here, whether the available water bodies and open spaces can address disaster management issues or not is the prime question".
He emphasized community organizations for the successfulness of plans, proposals and also presented the lack between different organizations. On this aspect, she says, *"About the successfulness of plan, it depends on organogram of organization and maintaining of a chain of command. Failure of most plans, proposals is due to not following the chain of command. Moreover, community organizations should be taken under definite organogram to address their problems from time to time as well as for directing the community in a proper channel and compelling them to follow policies, rules, and regulations (waterbody and wetland conservation act, open space act, etc.)".*

6.3 SWOT Analysis

The greater problem at the urban scale is the result of problems faced at the community scale. The problems laying within the community, their weak points, opportunities, and threats regarding the use and potentiality of open spaces and water bodies have been found out in order to get to the root of problems at the urban scale. Thus, the study focused on the community and the key findings from this study have been summarized below:

Strength. Community institutional arrangement, locational accessibility, effective ward council, active participation and eagerness of community people for using open spaces for disaster management are the major strengths of the community. These are the qualitative and potential factors of the community to reverse the present poor situation of community open spaces and water bodies.

Weakness. Lack of local level policies and acts, lower integration with central authority, high infrastructural development and lack of proper knowledge are the main weakness of the study area. Although the week points are clear, it will be hard to address when these are taken to practical field.

Opportunity. Positive influence of individual and other responsibilities for development and effective use of water bodies and open spaces, the willingness of local authority for open space preservation and development open the door of opportunities for the development of open spaces.

Threat. Poor management and rapid reduction of open, lack of intra and inter sectorial coordination, Lack of information and capacity building programs, no rules over private community open spaces, Rapid activities of development by the building developer group are the major threats.

7 Recommendations and Conclusion

7.1 Recommendations by Key Personnel and from the Community

Analyzing the study and recommendations by different key personnel's, experts, and community people some proposals have been presented below:

1. At first, clear documentation of the potential open space and water bodies is must require. A specific plan integrating disaster management strategy should also be developed.
2. The main problem of waterlogging is dead end drainage structure and no outfall of existing drainage. So, first of all, drainage outfall should be well structured. In that case drainage foe, rainwater flow outfall can be at water bodies.

3. Immediate actions must be taken to stop ongoing open space reduction and pond filling activities. And unused open spaces must be made usable. Same as for water bodies.
4. Rehabilitation can be ensured during fire emergencies in community open spaces.
5. Much greeneries at community open space can increase groundwater infiltration.
6. Reserved waters from water bodies can be helpful to manage emergency water needed for any fire incidents.
7. A bottom-up planning approach must be encouraged for the best practice of community open spaces.
8. Community organizations (private) should be linked with the higher organization (government) through an intermediate organization, so that help, when requires can reach the needy people. In that case, each and every organization should strictly follow the chain of command. NGOs can also cooperate with community organizations. It is very possible if community organizations are taken under a specific organogram.
9. In the case of community organizations, Ward Disaster Management Committee (WDMC) can be formed that will perform different types of awareness programs and help the community when a disaster occurs. Besides, School Disaster Management Committee (SDMC) can be formed where students will learn pre-disaster, during disaster, and post-disaster activities.
10. There should be transparency, accountability within organizations so that the case of corruption can be minimized and acts, laws, and policies can be established in practices. In this way, people will be compelled to take actions according to the waterbody and wetland conservation act, open space acts, and all other relevant acts as well.
11. Community organizations often suffer from lack of funding, though it depends on the community people's participation, here requires the intervention of the government.
12. Water bodies can be used as natural outfall of drainage following the topography.
13. Providing a water-reservoir tank at a specific height (so that it is out of reach of children) in open spaces can be used for the collection of rainwater that may be useful for any fire incidents. Govt. provided fire hydrant can be placed at community open spaces for ensuring easy accessibility and access.

7.2 Conclusion

Development of planning policies introducing disaster management strategies for any area development is giving priorities in recent years. In that case, the community-based disaster management plan policy development can be one of the most effective planning tools. While the traditional disaster management approach requires much time and has a high potentiality of failure of the plan, the community-based approach helps to find the root cause of the problems and also helps to find out the most reliable solution to the problems. The participatory approach helps to empower the community and helps to make them believe that they are also a part of the comprehensive planning procedure [6]. This process helps to create self-respect, ownership, accountability, and awareness among the community people [3]. It also finds out the importance of community institutions in disaster management plan policy development and execution [2].

Having huge scope of the study, there have some limitations also. Although most of the community people agreed to use the open space for disaster management purposes, some of the people opposed the proposal. They do not think that the places have so much potentiality. Sometimes lack of knowledge and awareness becomes a great challenge towards participatory plan development. Some the recommendations were given on the basis of community capacity, risk assessment, taking expert opinion survey, key informant survey, and community opinion to prevent waterlogging and fire hazard issues open spaces and water bodies. So, this well structured study methodology may be applicable to other areas as well to minimize the disaster risk and also to take necessary steps at disaster time emergency situation and post-disaster activities as well.

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Approach to Simulate the Rainwater Runoff at Site Level Using Rhino Grasshopper

Naga Venkata Sai Kumar Manapragada and P. C. Icy

Abstract The world community is presently facing the early impacts of Climate change. The floods have today become the new normal, natural hazard which has been most expensive and devastating. The Intergovernmental Panel on Climate Change (IPCC) has projected the gradual increase in global precipitation exceeding 0.05 and 0.15 mm day^{-1} for Representative Concentration Pathways (RCP) 2.6 and RCP8.5 scenarios, respectively. The major threat from the projected future phenomena is for megacities. The increase in the built environment with impervious surfaces in urban areas have been choking the naturally formed stormwater channels that usually lead water to surface water and aquifers. Flooding thus becomes more pervasive and hazardous in urban areas in comparison to rural areas. The Landsat and Radarsat data are commonly used to determine the spatial and temporal distribution of floods at the urban level. However, the cause for the blockade in runoff conveyance networks at the site level or street level becomes challenging. The simulation of site surface stormwater runoff for possible rainfall scenarios could aid the architects and urban designers to account for water inundation due to terrain and other site objects. Measures to avoid the conveyance networks blockade could be achieved by geospatial visualization of simulation results. Therefore, this study presents an approach to model and simulate the rainwater runoff using Rhino Grasshopper (Rhino-Gh) and Rainwater + tools. Detailing the approach in the tool facilitates the architects and urban designers to inculcate the assessment as a part of the early design analysis.

Keywords Climate change · Floods · Simulation · Rhino grasshopper · Rainwater +

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1 Introduction

Climate change (CC) concerns have heightened in the world community after its early impacts experiences. Every social, cultural, traditional, economic and technological system on earth is either directly or indirectly connected to climate. Thus, predicting the impacts, risks and vulnerabilities become necessary to recognize the mitigation and adaptation measures. The urban regions of today are considered a complex socio-technical system, which is densifying rapidly. The fifth assessment report [1] published by Intergovernmental Panel on Climate Change (IPCC) infers that the CC would broadly impact a broad spectrum of infrastructure systems, services, ecosystem services and the built environment in cities. The two majorly known global threat with the CC is the increase in ambient temperatures and precipitation. The IPCC [2] has projected the gradual increase in global precipitation exceeding 0.05 mm day^{-1} and 0.15 mm day^{-1} for the Representative Concentration Pathways (RCP) 2.6 and RCP8.5 scenarios, respectively.

India being a tropical nation and the peninsular region, floods are usually experienced during monsoons. Several studies conducted in recent times [3 , 4] have observed the increase in the frequency of floods in India. The studies have also been inferred [5 , 6] that the frequency of flooding has been increasing in India with the increase in air temperature. The increase in mortality and morbidity along with economic losses is associated with extreme precipitation events [7]. Major cities in India are located in coastal belts and seashores and face urban floods [8]. The increase in the impervious surfaces in urban areas [9] interrupt the stormwater runoff networks causing the inundation. The stormwater runoff, drainage pipes and catch basins for building and site level projects are usually calculated and designed by the hydrology engineers. The participation of hydrology engineers is mostly nil or passive for small-scale projects that account for the significant stake in urban fabric configuration. There is a need to integrate stormwater management during the conceptual design phase for a low impact design (LID) development.

The geospatial distribution of floods assessment is performed using Landsat and Radarsat data [10]. The Geographic Information System (GIS) is a standard tool used to capture and analyze geospatial data. The Landsat and Radarsat data in GIS aids in mapping the flood extent and depth for a chosen location. However, the GIS-based approach would not be applicable to.

- Assess the site-specific stormwater runoff directions
- Predict the deviations in the stormwater runoff directions for the changes proposed
- Recognize and evaluate the key locations to integrate the LID practices

The simulation of urban rainwater runoff and assessment of potential LID practices with respect to the context and climate of a location serves the architects, Landscape and urban designers to mitigate flooding at the micro and meso levels. Such dynamic processing and representation of the geospatial data are termed geospatial analytics. Geospatial data science requires knowledge in programming languages, database management, cloud computation, Artificial intelligence and

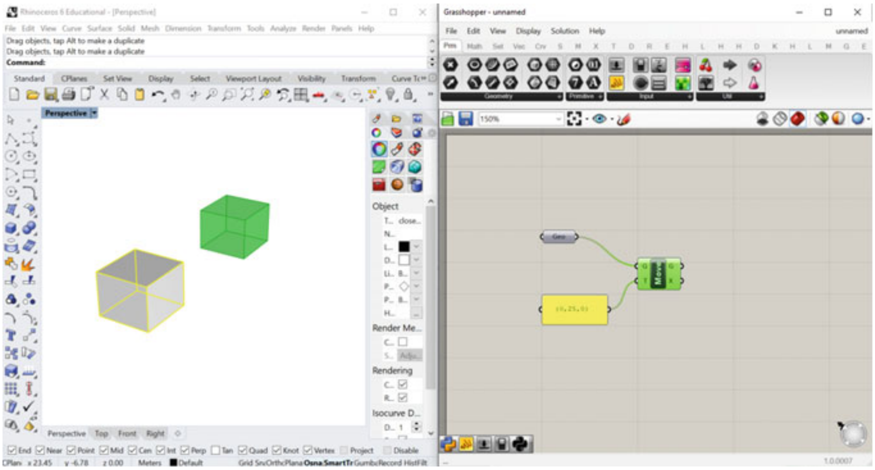


Fig. 1 Rhino interface (on the left) illustrating one cube modelled manually and another cube generated from Recipe created in Gh (on the right)

Machine Learning [11]. Stakeholders from different disciplines can avail the above mentioned five skills with available e-learning resources. However, the visual scripting tools such as Rhinocerous Grasshopper (Rhino-Gh) with its geospatial plugins enable the enthusiasts to perform geospatial analytics without the five skills.

The Rhinocerous (Rhino) [12] is the non-object-oriented modelling tool where designers from different domains can digitally model their conceptualized objects. The Grasshopper (Gh) is a plugin of Rhino that enables algorithmic modelling in Rhino through its visual programming interface (Fig. 1). The computational logic created with components available in the Gh is usually termed as Recipe.

The experts from remote sensing and GIS disciplines with programming interests are developing their plugins to compute, automate, simulate, analyze and visualize the information. The Rainwater + [13] is a recipe that has been designed to assess the stormwater runoff for a given site level or urban level geographical inputs. The Rainwater + allows the users to perform terrain analysis, runoff volume calculation, sizing and assess LID practices' performance. The tool uses Curve Number (CN) method [14–16] developed by the United States Department of Agriculture. The following Eqs. (1), (2) and (3) describe the CN method.

$$P_e = \frac{(P - I_a)^2}{(P - I_a) + S} \tag{1}$$

where

P_e = Depth of effective precipitation.
P = Total rainfall depth in storm event.
I_a = Equivalent depth of initial abstractions.

S = Maximum possible water retention

Equation (1) has been transformed into the following Eq. (2) as the Natural Resource Conservation Service data analysis inferred that on average, $I_a = 0.2S$.

$$P_e = \frac{(P - 0.2S)^2}{(P + 0.8S)} \tag{2}$$

where

$$S = \frac{1000}{CN} - 10 \tag{3}$$

and CN is the runoff curve number

The cover description of curve numbers for hydrological soil groups have been by Cronshey et al. [14] in his article. The Rainwater + tool refers to that curve number table based on the user inputs related to the land cover condition and soil type of the surface. Although the tool can assess the LID systems such as Bioretention, Subsurface infiltration system, Permeable pavement, Green roof and Rain harvest with capacity limitations [13], the major constrain is the precipitation input. The Rainwater + tool available only comprises percentile data and recurrence interval data inputs of 13 major cities in the United States of America. The users from outside of these 13 major cities of the USA cannot use the tool unless they possess the historically extreme years' hourly precipitation data. Thus, the present study aims to discuss an approach to model and simulate the rainwater runoff using the Rainwater + tool in Rhino-Gh. The objectives of this study are to analyze.

- The deviation in the stormwater runoff for a natural terrain versus the modified terrain scenario
- The inundation due to proposed changes in the site in the modified terrain scenario

2 Methodology

2.1 Site Selection

As shown in Fig. 2, an institutional site located in the outskirts of Mangalore has been chosen to demonstrate the simulation approach. Mangalore is a west coast city of India vulnerable to disasters such as Floods and Tsunami. The site chosen for this study is less vulnerable to Tsunami compared to floods due to its distance from the high tide line zone. According to the National Building Code of India [17], Mangalore belongs to a Warm-Humid climate. Precipitation in the form of rainfall can be observed in Mangalore for four to six months a year. The site chosen is characterized by the slope declining from the Northeast to the Southwest in direction.

Fig. 2 Selected site location and its contours

The interval between the two successive contours shown in Fig. 2. is 0.5 m. The total site area is 5.54 acres.

2.2 Precipitation Data

The hourly rainfall data has been obtained from the Global Precipitation Measurement (GPM) Mission of NASA (National Aeronautics and Space Administration) for the chosen site. The GPM [18] mission is the successor of the Tropical Rainfall Measuring Mission (TRMM) that provides the next generation of global observations of rain and snow sourced from the international network of satellites. There are nine websites and tools available to download the GPM and TRMM data. The five years (2015 to 2019) of historical weather data [19] with 0.5° × 0.5° spatial resolution and sub-hourly temporal resolution has been downloaded from NASA Goddard Earth Sciences (GES) Data and Information Services Center (DISC) [20]. The five-year sub-hourly precipitation data was available in 80,440 NetCDF4 file formats. Thus, a python script has been generated to compile and export the rainfall data into Comma Separated Variable (CSV) file format.

Boxplots have been generated to recognize the year having the maximum outliers from the precipitation dataset. As shown in Fig. 3. the year 2018 possessed maximum outliers in comparison to other years. Further analysis of precipitation data for the year 2018 has shown (Fig. 4) extreme precipitation even in May, which is three times higher than in previous years. The day-wise assessment (Fig. 5) of precipitation data for May in 2018 has inferred extreme events between 25 and 30th.

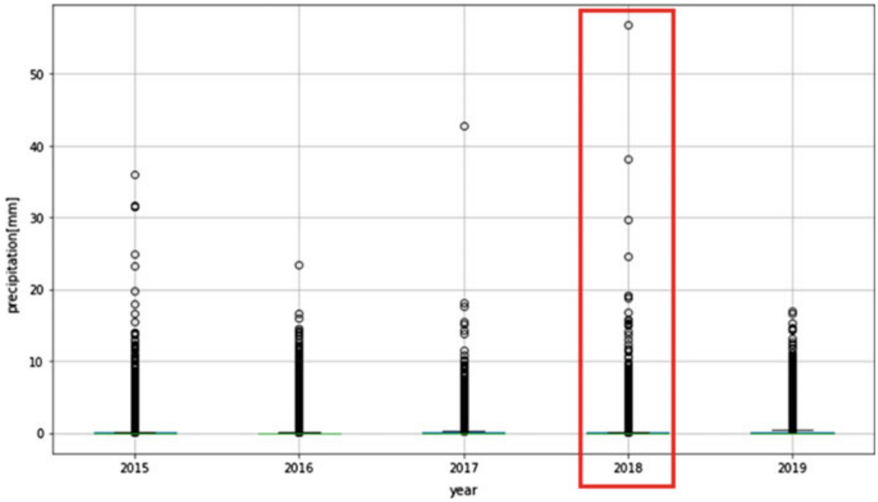


Fig. 3 Showing year-wise boxplots for precipitation data

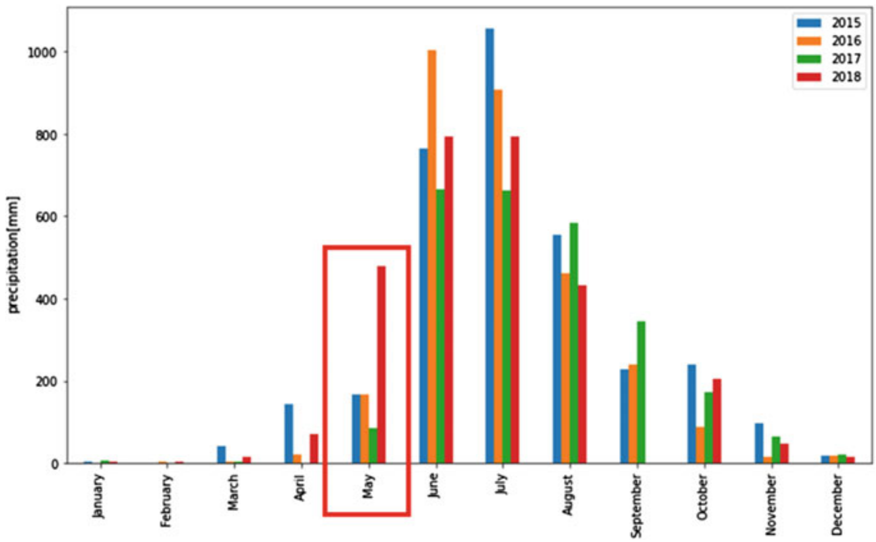


Fig. 4 Showing month-wise cumulative precipitation from 2015 to 2018

2.3 Validation

Although the GES DISC data has shown the extreme event between 25th May and 30th May of 2018, there was a need to validate using historical evidence. The study has discovered few media reports [21–23] that confirmed the extreme event in the

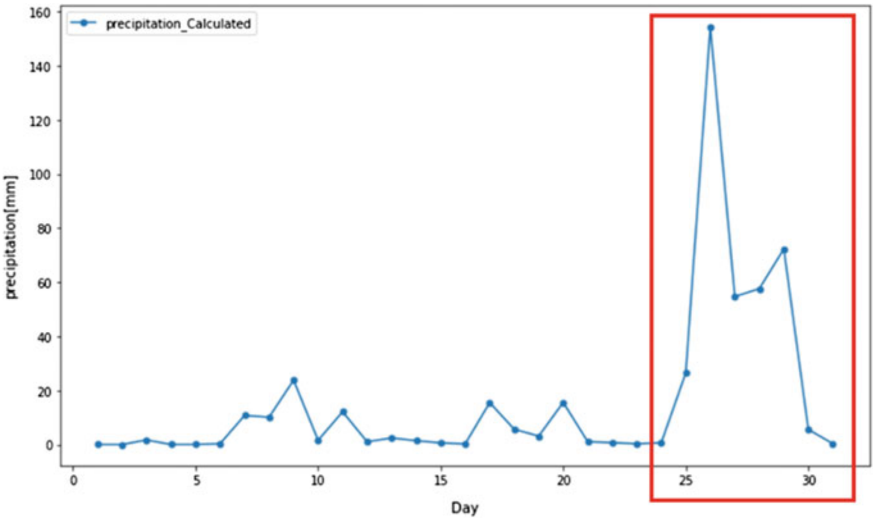


Fig. 5 Showing day-wise precipitation for May 2018

same timeframe. This paper assumes the extreme event occurred to be assumed as a typical event of future climate.

2.4 *Model Inputs*

The study considered two scenarios for the site. The first scenario considers the site's natural terrain topography, while the second scenario assumes built forms and other hypothetical changes to the site's topography, as shown in Fig. 6. Thus the first scenario will be referred to as a natural site and the second scenario as the proposed site. The Rainwater + interface requires the annual hourly precipitation data, 3D

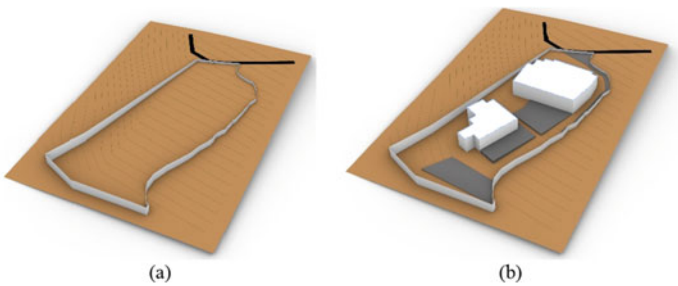


Fig. 6 **a** DTM representing natural site; **b** DTM representing the proposed site with impervious pavements and buildings

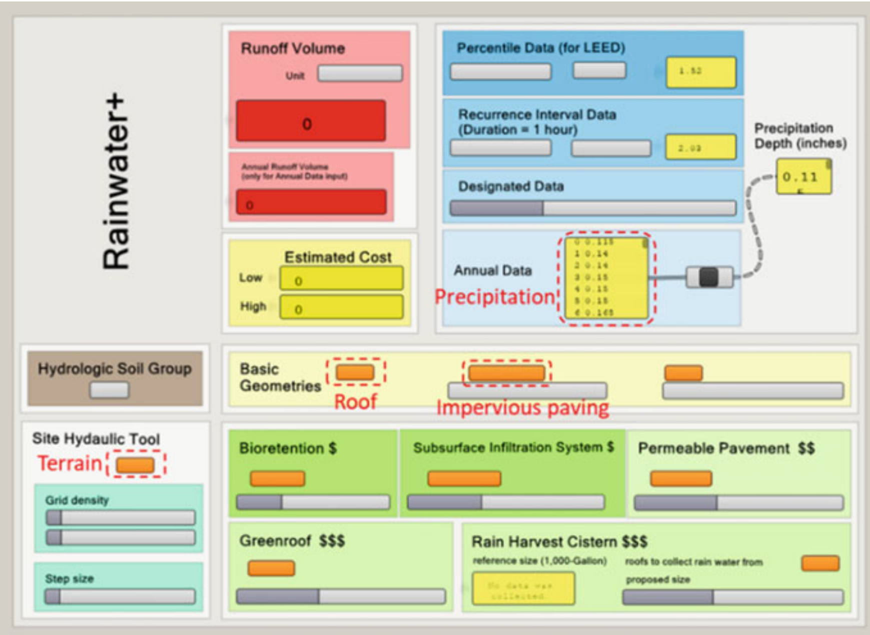


Fig. 7 Highlights the Grasshopper components available to provide numeric, 3D and 2D model inputs for simulation

digital terrain model (DTM) and 2D surfaces of roads, pavements, roofs and other site features as highlighted in Fig. 7.

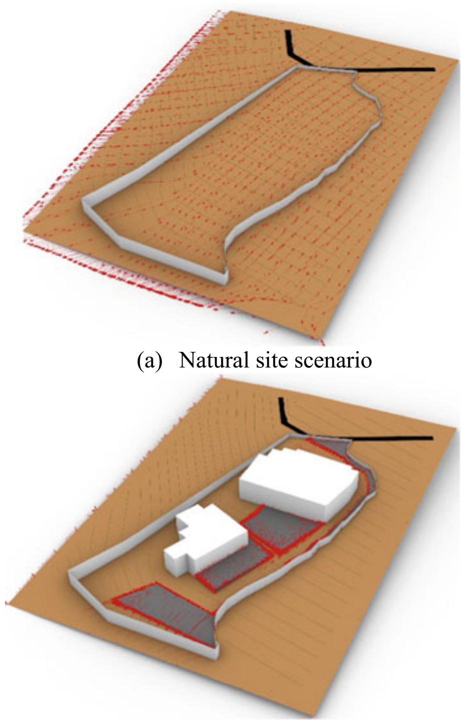
The method to obtain the annual hourly precipitation data for an extreme year has already been outlined in sub-Sect. 2.2. The 3D DTM for the site scale spatial resolution can be modelled in Rhino with contour maps or by directly importing from the 'Location' plugin of the SketchUp tool [24]. The urban level spatial analysis, the 3D DTM could also be imported from the Shuttle Radar Topography Mission (SRTM) of NASA using Digital Terrain Mesh (DiTeMe) [25] plugin in Rhino-Gh. The rest of the 2D surfaces could be modelled in Rhino through the modelling tools available.

3 Results and Discussion

3.1 Runoff Direction

The stormwater runoff simulation for both the site scenarios has been performed to recognize the critical flow direction. As shown in Fig. 8a, the flow's critical cardinal direction is the Southwest direction for the natural site scenario. The boundary wall

Fig. 8 Shows runoff direction for both the site scenarios



(a) Natural site scenario

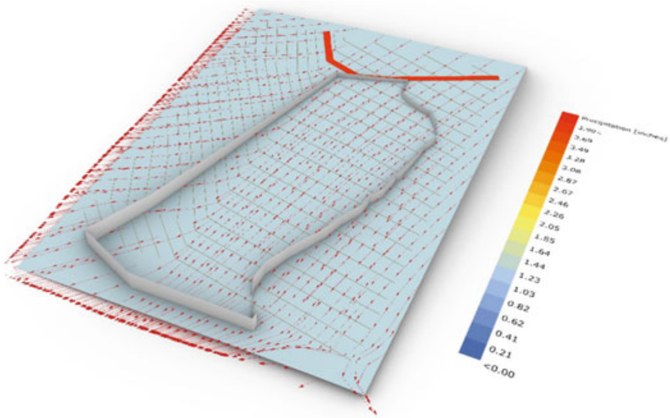
(b) Proposed site scenario

has not been considered by the tool. Else, the inundation could have been presented by the tool in the form of clustered arrows.

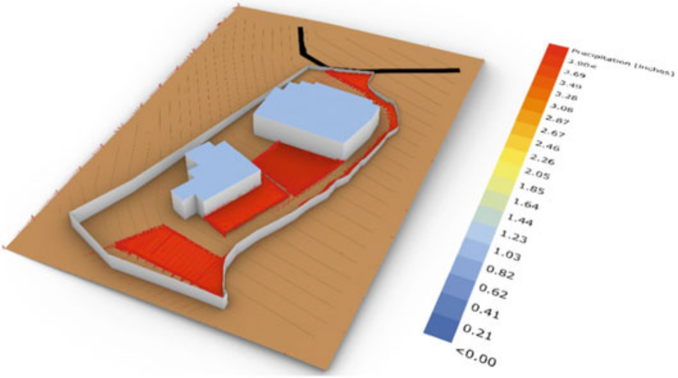
The clustering, however, can be observed in the proposed site scenario. Considering the buildings, roads and pavements as part of morphed terrain, we can see the inundation in the form of red coloured arrows cluttering at the edges in Fig. 8b. The need for stormwater runoff channels around the impervious built forms can be observed. The suitable location for rainwater harvesting could also be recognized from the stormwater runoff direction presented in Fig. 8b.

3.2 Rainwater Inundation

The site possesses the B group type of soil as per the United States Department of Agriculture classification. The study observed nearly 1.0 to 1.23 inches of precipitation depth on site for the precipitation intensity considered in the natural site scenario. However, the site approach road is predicted to have more than 3.9 inches depth of precipitation, as shown in Fig. 9a. The internal road and building frontages are also predicted to have more than 3.9 inches of precipitation depth (Fig. 9b) due to their



(a) Natural site scenario



(b) Proposed site scenario

Fig. 9 showing the rainwater inundation on the previous and impervious surfaces on site in both scenarios

imperviousness. The rooftop, however, was observed to have less precipitation depth similar to that of an open site. The higher precipitation depth noticed in roads, pavements and frontages of buildings need to be addressed by the site designers. The friction loss between the vehicle tire surfaces and the road is very much possible with such high precipitation depth. Similarly, the chances of pavement users being carried away are also possible with such high rainwater inundation on pavements. The permeable pavements and roads could be a resourceful measure to avoid accidents with rainwater inundation on roads and pavements.

4 Conclusion

The CC is evident and the increasing weather extremities pose a significant threat to the natural and human-made ecosystems. Along with global warming, the increase in flood disasters has become a serious concern. The vulnerability of floods is higher in urban centres due to the increased footprint of non-pervious surfaces. The stormwater runoff assessment for site level and urban level is essential to reduce the disturbance to the natural stormwater runoff conveyance networks. The state-of-art 3D modelling tools such as Rhino-Gh and Rainwater + recipes enable the architects, Landscape and Urban designers to simulate the precipitation depth and stormwater runoff direction specific to the given site conditions. The significant gap identified is the unavailability of default extreme year precipitation data for every location. Thus, the present study demonstrated an approach to avail the extreme year precipitation data and simulated the DTM for the chosen location and its scenarios. Dissemination of this approach could help the landscape and urban designers integrate LID practices in the pre-design phase. Following this approach at the pre-design stage of site design and development can ensure reduced site stormwater inundation risks and urban flood disasters.

5 Limitation and Future Scope

Usually, the CN method forecasts runoff volume but not the peak runoff. However, as mentioned in the Validation sub-section, the study assumes the present extreme rainfall scenario as a future business-as-usual scenario. The study observed the need for scripting expertise to extract the location-specific extreme year precipitation data. Additionally, the study observed the use of the old Gh components in the Rainwater + recipe. Thus the authors of this paper are in the process to.

- Develop extreme year precipitation database for the Indian locations
- Script the Rainwater + logic as Gh components to reduce the need for more computation power for simulation.

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Applications of AI in Health Monitoring of Structures in Potential Seismic Areas—A Review

C. P. Ginan and B. R. Jayalekshmi

Abstract Artificial Intelligence (AI) can be used to solve complex problems in civil engineering which involve time-consuming and arduous tasks, such that, the hurdles that appear when these works are completed using mere human labour can be completely overcome, by employing various techniques of AI. Furthermore, where testing fails or is hardly possible, AI can suffice the required design. AI can be of its best use when applied to the field of Structural Health Monitoring (SHM), which serves to identify and detect the current state and behaviour of structures. This article outlines the applications of AI in SHM in potential seismic zones. SHM functions in seismically prone areas by evaluating on field, the resistive power of a building against earthquakes and simultaneously it's potent to carry forth the services. The paper studies certain observations from research conducted during past few decades on development of artificial intelligence in SHM technologies in seismically intensive areas, in case of multistorey buildings, bridges, special structures and lifeline structures. The article begins with a brief introduction to artificial intelligence, further, detailing applications of AI in SHM in seismically prone areas. Subsequently, the contemporary applications of AI in the field are reviewed, alongside, the adaptability, sufficiency and potentiality of those methods to overcome the barriers of the conventional methods are discussed.

Keywords Artificial intelligence · Structural health monitoring · ANN · Potential monitoring · Damage prediction · Bridges

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1 Introduction

Civil structures are very important to be monitored for damage prevention as it houses people and facilitate the activities of mankind. The strength of engineering structures depletes with age and by natural disasters. Each structure must be monitored and its current state and behaviour need to be predicted. Prediction allows us to find the damage zones of the structure so that we can concentrate on such zones. Post-earthquake monitoring shall also be performed to know whether the structure is safe to take loads further or if the damage is propagating in the structure.

The application of AI in monitoring the response of structures in seismically potential zones is the focus of this article. Civil engineering can be an ideal field where AI can be applied. This is because, by feeding into a machine, the same level and amount of data that any experienced, talented and expert civil engineer possesses, AI can exhibit an accurate and precise outcome, as expected from the said human expertise with lesser human effort. AI is being used in all fields, from design to the monitoring of structures. Mathematical methods are used for structural monitoring such as EDMS (Earthquake Disaster Management System) had been in use for a long period of time, but AI provides a better method with the development of technologies such as pattern matching, which is very complex for human brains. Prototype models are created and placed on a testing plate upon which artificial seismic load is applied. Then, artificial data are recorded for training AI for future earthquake responses. Notably, this technology can be employed to detect earthquakes of the kind that we have never witnessed to date.

This paper reviews the prediction and health monitoring of structures, multistory buildings, bridges, underground structures and liquid storage tanks. The AI methods discussed in this article are Artificial Neural Network (ANN), pattern recognition, machine learning and genetic algorithm, in which ANN is predominantly used. Further, ANN with different architecture giving different precision are discussed. The use of wireless sensors and automated AI software has made permanent monitoring a reality. The damage effects of both static and dynamic load on the structure and monitoring based on dynamic behaviour are also discussed.

2 Artificial Intelligence

Artificial Intelligence (AI), a modern technology that started its development in the 1950s, attributes to machines, human intelligence and behaviour, seeking to solve problems without complex human interventions. It can be described as a set of various technologies that enable machines to act and comprehend with intelligence in a human-like manner. AI ascribes to almost all the components of human intelligence, focusing on reasoning, perception, problem-solving, learning, etc. From Alan Turing's test to determine if a machine really is intelligent, to its official emergence in 1956 that introduced applications of AI which contributed to proving mathematical theorems and later to the programming language and finally to the development of a Project Debater that helps people argue with proper evidence and with little bias or ambiguity—Artificial Intelligence has emerged to be a very promising field of study. AI, when considered as a set of various technologies, the subset of this wide pool of study includes Machine Learning (machine learns and reprograms itself) and Deep learning (a subset of machine learning that uses neural networks with multiple layers). With these subsets and various other classifications like strong AI and Weak AI, Artificial Intelligence, in general, engage itself in speech recognition, Neural language processing (NLP), image recognition, real-time recommendations, etc. Image recognition is a major application of AI that identify and distinguish images, texts, object, or people (moving or non-moving). Pattern recognition is another sign in the field of artificial intelligence, that makes use of machine learning data to segregate data by performing special algorithms.

2.1 Machine Learning

Machine Learning, being a branch of Artificial Intelligence, seeks to build applications that can improve its accuracy of prediction or decision-making over time, that is derived from learned data, independent of programming to do so. Here, features and patterns are found out by equipping with trained algorithms, such that predictions and decisions are made with respect to new data. Machine Learning works basically in four steps. Once a training data set is chosen and prepared for, then an algorithm would be chosen for the training data set. The choice of an algorithm depends on the data type, whether it is labelled or unlabeled.

2.2 Artificial Neural Network

A major tool employed in machine learning, Artificial Neural Network (ANN) systems that intend to mimic human learning. These are structures that replicate the organizational principles seen in the brain. Pattern recognition, function approximation and classification are the areas in which ANN is applied to its best. In ANN, human brain-like structure is achieved as neuron nodes are interconnected like a web, each neuron, being made up of a cell body that is accountable for information processing while they carry information through inputs and outputs. First, the ANN undergoes training to learn pattern recognition. ANNs are of two different topologies, namely, Feed Forward and Feedback, in which, the former is used in pattern recognition, generation, or classification, with fixed inputs and outputs. Various strategies, classified as supervised learning, unsupervised learning and reinforcement learning, are employed for ANNs to be trained. A training or learning algorithm called the Backpropagation (BP) Algorithm, which learns with example is employed and is ideal for pattern recognition. ANN constitutes layers that are categorized into three—An Input layer, Hidden Layers and Output layer. ANN is a typical case of weighted graphs; the inputs and outputs are calculated based on the artificially assigned weights of the data. The input signals are received as patterns and images as vectors by ANN and these inputs are mathematically represented as notations. Each of these inputs is multiplied by their weights to solve the problem to obtain output signals, as each weight represents the relation between the input and the process.

Wavelets Transformation, Nonlinear Time history analysis (NTH) and Principal Compound Analysis (PCA) are applied with AI for better results. PCA is used along with AI, so that huge data is compressed. The compressed data can be then, easily processed by AI. The best performance of the AI method is evaluated based on Mean Scale Error (MSE), Regression and CPU time. When the data recorded contains noise in it, PCA helps to remove the noise, which in turn, helps to improve prediction.

3 AI in Structural Health Monitoring

Generally, all the references related to AI use similar methods other than articles that mention pattern recognition and genetic algorithm. This paper, therefore, mainly focuses on the applications of AI that employ methods that stand out from the rest, for example, those applications that combine AI with many other technologies such as PCA, NTH, wavelet transformation, etc. Differential factors that come with the data used for training, testing and validation are the next distinguishing feature that this article tends to look upon. When some articles used real recorded data, the other articles derived data from prototypes. Most of the references in this article use ANN but with differences in its architecture such as changes in the number of layers in the input, hidden and output layers and the number of neurons used.

4 Prediction of Damage

Prediction of the damage induced by earthquakes was a hard job for engineers. Two methods were mainly used for it, Seismic vulnerability curves and nonlinear Finite Element Method (FEM). In that FEM can only be used to assess a single important structure in any analysis process and as the number of structures increases the method becomes ineffective and time-consuming. Seismic vulnerability curves are better than FEM and can be applied to a class of similar structures but this method only takes a limited number of structural properties and ground motion is described using only one single parameter. If dissimilar structures want to be evaluated such as structures with a different number of stories or bays, this method cannot be applied. These shortcomings motivated the researchers to find a method that is more efficient and can be used on different classes of structures and use a broader number of parameters to label ground motion. As a solution for this ANN was used, to represent both the ground motion and structure using a greater number of structural properties and ground motion parameters. ANN was trained for various time periods of an earthquake and it was used to predict maximum response in a single-story structure directly to the matching time period [1]. Simulation was done using feedforward and Error Backpropagation Training algorithm with one hidden layer with varying nodes, consisting of one input layer and one output layer, it was understood that the response was good. If the network is trained for different time periods of an earthquake, then this model can be used to predict the response of the corresponding time period of an earthquake whose data were not been used for training the network. The analysis [2] was made on two-dimensional (2D) RC frames with different damping, stiffness, topology and strength and were subjected to different magnitudes of ground motions and the response data was used for predicting the seismic damage. The performance of ANN was tested using many examples and ANN was almost successful inaccurate prediction. The above articles were published before 2009 and it was at the early stage of AI application in seismic damage prediction. The author also explains that the ANN cannot be used in a place where we lack data such as previously unseen earthquake is a challenging task, as ANN studies from the data input and it interpolates between these data and gives the result but any extension would require additional data for training. After this article has been published, many scientists have worked in this field and made many discoveries using models and the data acquired within this period.

Method for prediction of nonlinear structural behaviour when earthquake load was applied using an adaptive scheme was reported in [3]. The prediction of damage using ANN can be applied in the performance based design framework, aiming at reducing computational cost when dynamic analyses were performed. The training of the ANN with different sets of data helps in the better performance of ANN. For the training purpose, artificial records were used, which were better than natural records as it produces more cycles of data and it produces nonexistent data which was helpful in training ANN for a future seismic event. Prediction by adaptive and non-adaptive schemes are examined by this article: (i) Non-adaptive scheme, is a method where ANN was trained once over the accelerogram data and the prediction of structural seismic response for all time steps was based on it. (ii) Adaptive scheme is where the ANN is trained once but the prediction was rectified by performing conventional NDA in certain predefined time steps. The performance prediction of the non-adaptive scheme was good in the case of structures with linear to slightly nonlinear but it produce unacceptable results when it was used for highly nonlinear structures. Small errors were accumulated and the result deviated from its real value but this accumulation was not present for linear structure. An adaptive scheme accurately predicts the behaviour of the nonlinear structure as it corrects the accumulated errors periodically. Resulting in highly accurate values as compared to the non-adaptive scheme.

4.1 Multistorey Buildings

The prediction of damage in multistory buildings is also calculated by ANN. Suryanita et al. [4] has investigated the use of ANN for the prediction of earthquake-induced damage state of buildings. For this, a 10-story building model was tested with earthquake loads based on the past time history record. The prediction of damage states was done using a backpropagation multilayer ANN in MATLAB toolbox. This ANN was trained using the time history of earthquake data load and the response of the model structure. There were 4 ANN architecture models tested with displacement, velocity and acceleration as input. Model 1 had all the above, model 2 had displacement, model 3 had the velocity and model 4 had acceleration respectively as input. Damage levels of the structure were the output of NN. The damage levels are categorized as Safe, Immediate Occupancy, Life Safety, or in a condition of Collapse Prevention. Among these models, the first model gives maximum accuracy of 95% and model 4 gives the least accuracy of 80%. All the models have an average accuracy of 85%. There was a total of nine sets of data in which eight sets were used to train ANN and the ninth set was used to check the accuracy of the trained ANN.

The basic 3-layer architecture of ANN was used to predict the damage, an input layer, hidden layer and an output layer were employed in [5]. Ground motion parameters of an earthquake were selected from 34 provinces as input parameters. Multistory building structures of RCC with shear walls were made as models for testing, three different building heights were used, 10 stories, 15 stories and 20 stories. Model response spectrum analysis was carried out to get the responses of the model structures. Thus 6345 data sets were obtained. This data was used to train, validate and test the ANN. The BP ANN architecture was used to predict the damage in which 3-layer architecture with 8 (only eight) neurons in the input layer, 2(only two) neurons in the hidden layer and 6 (only six) neurons in the output layer. The main output parameters of ANN are velocity, story acceleration and story displacement. For training ANN, a total of 6345 data sets were used in which, 72% of data sets were used to train ANN, 14% for validation and 14% for testing. The trained ANN performance was evaluated and a 96% rate of prediction was achieved.

Damage prediction of the multistory building was reported in [6] as a task for Multilayer Neural Network and was time-consuming. Hence Functional Link Neural Network was used for better prediction of seismic response of tall shear buildings. "A Functional Link Neural Network (FLNN) is a single-layer neural network where the hidden layer is replaced by a functional expansion block for enhancement of the input vectors. FLNNs are highly effectual, computationally more efficient and faster learning than multilayer neural networks (MNNs)" [6]. FLNN consists mainly of two parts, one was a learning part and the other was a functional expansion part. FLNN uses ground acceleration data as input and response of each story of a multistory structure as output. The structural response of the multistory building was predicted using FLNN and the polynomial used in the expansion block of input vectors for the enhancement are Legendre and Chebyshev polynomials. When results were compared, FLNN is faster than MNN as FLNN does not have a hidden layer.

In FLNN, to minimize a given cost function, the weights were updated. The weights were updated using Error backpropagation algorithm. A feedforward and error back-propagation algorithm was used for learning. the MNN uses 3-layer architecture input, hidden and output layer. An error BP algorithm was used to train MNN. The conventional method of MNN takes more time to execute complex earthquake data and FLNN was developed for the main purpose of executing such complex data with a minimal amount of time. In testing, FLNN proves to be a better method as it is more accurate in predicting the response. Prediction was then developed by Convolution Neural Network [7] making it more precise.

5 Damage Identification

The position of damage on the structure by seismic load can be identified by using image processing of AI. The damage of reinforced concrete column was automatically identified using Region-based Convolution Neural Network (RCNN) image processing. An interactive labelling process was done automatically by MATLAB. For learning, 400 images of post-earthquake damaged images taken by consumer-grade cameras were used. [8] reported that the trained RCNN can automatically detect the multitype seismic damage up to a precision of 80%. Convolution base along with region proposal network (RPN) and an RCNN Module makes the RCNN faster. The faster RCNN thus produced detects and identifies the damage in the image and it produces the rectangular bounding boxes around the damaged part. When an image is inputted, the output is of the image with rectangular bounding boxes showing the damaged part of the structure. The fast RCNN predicts whether the input image presents any damage which is among the four types of damage, rebar buckling, rebar exposure, concrete spalling and concrete cracking based on training data.

5.1 Buildings

The structural damage identification was carried out by Ni et al. [9] using measured Neural Network (NN) and Frequency Response Function (FRF). In this article, a 38-story reinforced concrete building with 1:20 scale was used as the model. It was tested on a 5 m*5 m shaking table by exerting earthquake loads. It was tested level wise with low to high damage, till the model was completely damaged. FRFs were generated from the above vibration for seismic damage detection. The FRFs obtained from the Polyvinylidene Fluoride (PVDF) film sensors were usually used to train the NN for prediction but as this FRF data was huge in size, computation of this data using NN causes the problem and reduces efficiency. And half use of this data would result in loss of valuable information, so this data was compressed using Principal Component Analysis (PCA). PCA filters the noise and reduces dimensionality. The compressed FRF data provides accurate identification. When damage identification is compared, PCA methods provides much higher accuracy than FRF method.

Using modal parameters and artificial neural network, seismic damage identification method was developed for steel moment-frame structures with regular geometry both in plan and elevation. It was a 2-stage process in which, the first stage was to calibrate the structure data such as mass and stiffness before seismic action or at the initial stage. The second stage was the evaluation of the final mass and stiffness of the structure after the seismic load was applied. A typical office structure, a 5-story building with 16 m*18 m dimension and a height of 4 m for the first story and rest with 3 m was used for simulation through a basic Finite Element Method (FEM) data the NNs were trained. The multilayer perceptron (MLP) and radial basis functions were used for damage detection by NNs. A 2-layer feed forward MLP was applied in this work. In this method, mass was considered an important parameter. The effect of modal data error was studied using Gaussian noise, as Gaussian noise was added to the modal parameters and the result was compared with the previous one, it is shown that the variation due to modal error should be less than 1% for a damage prediction of 95% [10]. The damage caused by seismic load in the braces of a steel structure is identified using Deep Neural Network [11]. The E-simulator data generation was used to train the AI.

Damage to the shear wall was detected using artificial neural network in [12]. The concrete shear wall helps in resisting the building against lateral loads. Pushover analysis which is also known as Nonlinear static analysis was the approach used in this method. Pushover analysis is a method that applies the lateral force of monotonically increasing nature on the structure till it fails or reaches a target displacement. A FEM model (nonlinear) of a 5-story building with shear wall was created and pushover analysis was applied to get plastic hinges and inter-story drifts. For inputs and outputs to the neural network, the inter-story drifts and plastic hinges were used. NN with single hidden layer and multilayer feed forward network was used. By trial and error method, the number of neurons in hidden layer was obtained. From these results, the MLP neural network predicts the damage of the shear wall when it was compared with nonlinear time history analysis values.

Vafaei et al. [13] demonstrates the damage identification of cantilever structure was done by using Wavelet Transformation (WT) and Artificial Neural Network. "WT is a time–frequency analysis based on a windowing technique, which employs variable-sized regions to decompose signals" [13]. There is a sharp transition in the dynamic response of a structure when the stiffness of the structure varies due to damage. There would be spikes in the decomposed signals which reflect discontinuity in signal when WT was used to check the damage. For damage identification, the seismic acceleration data was taken from a strategically selected location. PCA was used to compress the decomposed data by WT which was used by ANN to predict the damage. The method was applied to a tall tower located at Kuala Lumpur Airport. This article employed multilayer feed forward NN also for damage identification. The result predicted by the method is reported as accurate and because of the use of PCA, there was very negligible effect of noise.

The Fuzzy Neural Network was used to predict the damage caused by the seismic action [14]. The acceleration data of earthquakes recorded were having errors, due to human or instrumental error, so this data was called Fuzzy and when this data was used to predict using NN it becomes Fuzzy Neural Network (FNN). A probabilistic approach to such data is limited as it requires a huge amount of data that may not be available in all parameters. The FNN cannot be used for negative data, which means bipolar data cannot be used in FNN. The bipolar data was converted to α-cut form and that data was used for training, later it was retransformed from unipolar to bipolar. Using this data FNN architecture was trained and the prediction was done. Once FNN was trained, it can be used to predict the damage due to real earthquake data.

5.2 *Bridges*

Permanent and automated health monitoring can improve information about long-term behaviour and the current state of the bridge. The permanently applied sensors continuously recording the measurement of the bridge help in permanent monitoring. ANN has been used to predict the health monitoring of bridges caused by earthquake acceleration [15]. Low intensity loads of ground acceleration were used to simulate numerical data. Feed forward and backpropagation algorithm was used in which acceleration data from sensors was used as an input and the output was the damage level of bridge. The damage level range from low to high; they are: (i) Immediate Occupancy (IO), (ii) Life Safety (LS), (iii) Collapse Prevention (CP). Usually, the analysis would be done after monitoring, that is the results obtained in the monitoring process and expertise engineers were required to do the analysis but the intelligent system created in this article monitors and analyses the bridge using ANN. There is no need to know how the monitoring works or input–output relationship, linear or nonlinear data, the ANN with an adequate number of hidden layer neurons can learn and approximate the damage. Using Visual Basic Programming Seer Monalisa-ANN was created which conducts the prediction process. ANN was trained using 835 acceleration data and it was tested with 234 data. For seismic health monitoring of bridges, ANN can be used successfully.

Peak Ground Acceleration (PGA) is a key parameter to check the damage of the bridges. ANN was used to estimate PGA at the site of 21 bridges with almost 500 m length [16]. The input for the ANN was local magnitude, focal length and epicentre distance. For better performance of ANN in the prediction of PGA, hybrid approaches like NN and a genetic algorithm can be used. The architecture of the ANN was, one neuron in the output layer and the hidden layer with three neurons was used to train and predict the seismic estimation analysis. 70% of data was used to train ANN and 30% was used to adapt and check the method. This ANN can only use the seismic data of Richter scale magnitude above 5.0 otherwise there would be unwanted noise. There are two methods to estimate PGA at the bridge location from the recorded seismic data. NN1 (model 1) was a simple method that takes the data from nearby station of the bridge and use weighting factors to obtain PGA at the bridge. NN2 (model 2) was a method where it finds the epicentre from the recorded seismic data and this new parameter was inputted to a weight based NN and the PGA was predicted.

This paper [17], aims to compare the performance of ANN with displacement and acceleration as the data domain, to identify which data domain predicts the damage more accurately. The ANN architecture uses 1-layer input, 1 and 2 hidden layers and an output layer. The output is of the bridge condition, values from 0–3, in which 0 stands for safe and 3 stands for high risk. The output bridge condition was predicted using a finite element analysis program. The study considered three spans of box girders on which earthquake load was applied. Displacement, velocity and acceleration were used as input. The linear behaviour of the piers was considered during the health monitoring of bridges due to the earthquake. The acceleration and displacement data domain were evaluated based on different parameters such as MSE (Mean Square Error), Regression (R mean), CPU time (running time). For a better method, the value of MSE should be less as it is the error in calculation, R means should be more; favourably value to be close to one which is 100% accurate prediction and the CPU time should be short. The best performance was achieved by displacement data domain with one hidden layer which gives an 80% regression. The monitoring of bridges using ANN was recommended to use the displacement data domain with one hidden layer.

This article [18] introduces the Nero-Genetic hybrid method to estimate the damage of bridges. It is a fusion of Artificial Neural Networks and Genetic Algorithm, for numerical modelling techniques. Genetic algorithm was used to optimize the acceptance of NN weight in Neuro-Genetic hybrid. In the hybrid, Back Propagation NN uses Genetic Algorithm to estimate the weights. For prediction by NN, it is not essential to have the input–output relation, it can be used for a nonlinear relationship between the input and output. Whereas the genetic algorithm uses selection, mutation and crossover operations. 70% of the data was used to train the Neuro-Genetic Hybrid, 15% for validation and the remaining for testing. The activation function, network architecture model and initial weight were the parameters on which the performance of the neuro-Genetic method depends. The best method for the prediction of damage due to earthquake load was the neuro-Genetic method with a sensor recording data system, which predicts 97% accuracy to the actual damage.

5.3 Underground Structures

The damage to underground structures due to seismic load is very dangerous. It is hard to evaluate the damage propagation in underground structures as it cannot take successive seismic loads. Ubiquitous Sensor Network (USN) are the sensors used to identify changes and for communication in the underground. Many such sensors form a network and detect the damage. The finite element model of Ulchiro- 3ga station was used to train and test the ANN. From acceleration data, the history of damage and damage pattern was obtained. The article [19] employs unsupervised learning recognition for statistical pattern identification. The change in the structure or the damage propagation is recognized on a timely basis so that the current state and behaviour of the structure can be predicted. When there was a high difference in acceleration amplitude between good and damaged conditions, the increase of stiffness degrading ratio was observed. The stiffness degrading ratio was increasing whereas the value of reliability interval was decreasing. When the stiffness degrading ratio is 40%, the methodology used in this study is useful.

5.4 Liquid Storage Tanks

ANN was used to predict the damage of liquid storage tanks in the seismic area [20]. For training ANN, response of strong earthquake experienced liquid tanks were used, a total of 240 sample data were taken in which 190 data were used to train the ANN and 50 for testing. Six parameters were used as input for the ANN, they were, PGA, tank height, tank diameter, liquid height during an earthquake, percentage fill and the output was the damage state of the storage tank. There are many input parameters, it was very hard to obtain a mathematical relation of this nonlinear and uncertain input data, which makes ANN a powerful tool in predicting the damage as it does not require any mathematical representation. The ANN model was constructed and trained using the back propagation (BP) algorithm. The supervised network was constructed and trained using MATLAB NN toolbox. It was concluded from this study that ANN can be used to predict the damage of the storage tank.

6 Conclusion

AI has improved the damage prediction from the Seismic vulnerability curves and nonlinear Finite Element Method (FEM), in which all the structural parameters were hard to be used in analysis and it was hard to apply for dissimilar structures. AI has been a breakthrough in health monitoring of structures under earthquake zones. Prediction is the main focus area in which AI is used in SHM in the seismically potential zones. The damages induced by the earthquake and whether the structure can withstand the seismic load or is it safe to carry a live load are all predicted with the application of AI. ANN is a favourite area of study under AI and its applications in SHM for researchers today. ANN makes the distinction between linear and nonlinear functions insignificant because of the process of self-learning that ANN conducts from the input and output data. ANN applied with other operations such as wavelet transformation, PCA, NTH, etc. helps in predicting a much higher precise damage state and deal with noise and complex data hazards. Data from previous records of earthquakes or from the new data obtained from the models created are used to train the AI. Around 70–75% of such data is used for the training purpose, 10–15% for testing and 10–15% for the validation process. Other than ANN, pattern recognition and genetic algorithm is used for damage identification.

Other methods of AI such as machine learning, deep learning, etc. are yet to be developed in SHM of seismic zones. It is still in the developing phase as it requires precise data. The present recorded data are not precise and accurate as it has errors due to human mistakes and equipment malfunctioning. The maximum accuracy to date obtained for a normal structure damage identification is 97%. However, it can be improved to much higher accuracy. The applications of AI in liquid storage tanks and underground structures are yet to be improved. The damage caused by earthquakes with higher magnitudes is still hardly possible to be predicted. The use of advanced sensors and much more advanced AI methods can jointly improve SHM in severe seismic zones and thus, automated seismic SHM can be achieved, which makes the structures safer and enduring.

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State-Funded Macro-Insurance Policy for Disaster Resilience: A Study on National Disaster Insurance Policy in Sri Lanka

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Abstract Natural hazard-induced disasters are a common occurrence in many parts of the world. Though preventive steps are taken to lessen the effects of disasters, disasters still have an impact on the country's social, economic and environmental aspects. Over the last decade, Sri Lanka has been affected by a variety of natural disasters. As a result of the catastrophic consequences of these incidents, more attention is being paid to disaster resilience. In 2016, 'National Natural Disaster Insurance Policy (NNDIP)' was established to cover for damages and compensate the victims of natural hazard-induced disasters. Although the policy was established, there are issues and challenges in the implementation and administration of the policy. To identify the issues and challenges, initially, literature was reviewed. To achieve the aim of the study which is to identify the issues and challenges in the NNDIP, a qualitative approach was followed with ten (10) expert interviewees. Content analysis was used to analyse the collected data. From the study, key challenges and issues were identified as loss adjustment and claim management, delay in processing claims, insufficient staff and lack of clear guidance on the claim process.

Keywords Disaster resilience · Insurance claims · Insurance policy · Loss adjustment · Macro-insurance · Post-disaster recovery

1 Introduction

Over the past decade, throughout the globe, disasters have increased enormously and it has affected the communities on a large scale [1]. The key reason for the increase of natural disasters is identified as climatic change [2]. Disasters such as earthquakes,

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Tsunamis, floods, droughts, storms, landslides create significant impacts on the lives of affected people in both social and economic aspects. Further, the government holds the responsibility to replace and repair infrastructure and allocation provisions for the least able victims of the disaster and it is considered to be the post-disaster role of the government [3].

Over the past years, a number of such disasters took place in Sri Lanka [4]. After the 2004 tsunami disaster in Sri Lanka, the need for a proper institutional structure for disaster management increased and, as a result, the National Disaster Management Centre was formed under the Ministry of Highways, Social and Health [5]. As per the authors [2], institutes related to disaster management in Sri Lanka has undergone several changes since 1995 and only after 2004 Tsunami disaster and these institutions and the overall disaster management process in Sri Lanka have received the most comprehensive reforms. Further, for the disaster reliefs, National Disaster Relief Services Centre (NDRSC) released the funding for relevant government authorities for reconstruction and rehabilitation until the introduction of National Natural Disaster Insurance (NNDI) policy in 2016 which was a major milestone in Disaster Risk Reduction (DRR) in Sri Lanka [6]. NNDI policy was introduced to Sri Lanka with the aim of compensating the victims of natural disasters. Though the policy was introduced to compensate the victims, there are issues and challenges in implementing the NNDI policy. Therefore, the study aims to identify the issues and challenges in the NNDI policy.

2 Literature Review

2.1 Disaster and Disaster Management

The number of disasters occurring worldwide has almost increased over the last three decades. Disaster can be defined as an event that is natural or manmade with a progressive or sudden occurrence that creates severe impacts on the affected community [7]. Moreover, authors [8] has stated natural catastrophe occurs when a significant geological, meteorological or hydrological phenomenon exceeds a community's capacity to respond to that occurrence. In addition to that, Jha [9] has categorised natural disasters under four categories, geophysical, hydrological, meteorological and climatological. Furthermore, through natural disasters, physical, social and cultural and environmental impacts take place [8, 10, 11]. Thus, systematic disaster management needs to be available in every country. Disaster management can be defined as the management of disasters and their post consequences through appropriate and immediate actions [12].

When considering the global context, Sendai Framework has been identified as the globally accepted framework for disaster risk reduction [13]. In the Sendai Framework for disaster risk reduction, four priorities for action, seven targets and 13 guiding principles can be identified [14]. Moreover, Sustainable Development Goals also look into disaster risk reduction [15]. Furthermore, USA's Federal Emergency Management Agency (FEMA) guidelines can also be shown as a guideline which helps for disaster management work where there are 14 emergency support functions to be followed after a disaster [16]. In addition to that, the Australian Institute for Disaster Resilience guideline (AIDR) provides a priority sequence of events in disaster management [17].

The government plays a major role in post-disaster management in countries. That is, by serving as the "last resort insurers" to reinstall the infrastructure and cover for private sector losses [3]. As per Petrucci [10], the government is "the most effective insurance instrument of the system". Further, the author has stated that the reason for this is the ability of the government to spread and diversify the risk over a large population. Moreover, [18] have highlighted that the objectives of international efforts to avoid or respond to extreme weather events are followed in order to protect human health and safety, the climate and the economic stability of nations.

2.2 *Disaster Management in Developed and Developing Countries*

2.2.1 Developed Countries

This role of the government is considered significant in developed countries. Around a third of the USD, 6.2 billion direct damages from the US midwest floods in 1993 were repaid by federal and state government assistance, according to reports [19]. Further, authors have stated after the devastating flooding of the Upper Tisza River in Hungary in 2001, approximately 1000 houses were completely rebuilt by the government. Additionally, Varangis et al. [20] have detailed the kind of taxpayer solidarity with flood victims is common for many mostly developed European countries. Kerjan and Kunreuther [1] also have highlighted the impact of insurance and government in the aftermath of catastrophes in developed counties mentioning they are playing major roles in ensuring economic and social resilience.

According to Linneroth-Bayer and Mechler [21], the involvement of government in assisting in post-disaster management varies even among developed countries. As per them [21], around 48% of the direct losses from 1997 floods were borne by the Polish government and only 4% of affected Kobe earthquake households in Japan from 1995 were covered despite having a national public–private seismic insurance scheme. Authors have stated that in both these cases government had to fund private victims despite having to reinstate damaged infrastructure. Whereas in the USA private sector insurance providers covered 30% of all private and public direct damages from the 1994 Northridge earthquake, while the federal government covered just 20% of total losses by helping state governments rebuild damaged infrastructure [21].

Most developed countries provide monetary compensation and post-disaster assistance to the victims often in state and private sector partnerships of insurers [21]. Further to them [21], official public–private insurance schemes for natural disasters such as flooding, earthquakes and all hazards have been enacted by many developed countries such as Japan, France, the United States and New Zealand. Authors have said that the National Flood Insurance Program (NFIP) implemented in the USA is a good example of this. This was done to expand the insurance industry's position in developing flood insurance policies whereas flood peril had been considered as uninsurable while taking all the risks to the government in the objective of passing the eventual risk to the industry and persons living in risky areas.

2.2.2 Developing Countries

Usually, low-income countries depend on government and foreign assistance to deal with severe floods [1]. Nevertheless, Linnerooth-Bayer and Mechler [21] accentuated the fact that the minimal support from the government in such counties. According to them [21], in developed countries, the scheme of government insurance and public–private partnerships is insufficient to fund low- and middle-income countries. Further, authors have highlighted the fact of the inability of residents of those countries to cover their risks through commercial insurance even though they are being backed by the government should be noted. Moreover, as mentioned earlier, the government is also unable to confront the liquidity deficit. As per Gurenko [22], in such situations, governments turn into international donors and development banks. Linnerooth-Bayer and Mechler [21] stated that still with international donors, governments of developing countries would struggle to confront the liquidity deficit apart from a few exceptions such as the Indian Ocean Tsunami disaster in 2004. This has resulted in half-complete projects and half-complete houses even many years after the reconstruction process in some instances [23].

Cohen and Sebstad [24] have stated the willingness of disadvantaged and oppressed people to participate in such processes must be considered in any discussion of how to facilitate risk pooling and transfer in developing countries. Reciprocal exchange, such as kinship links and group self-help, are the alternatives available. As per authors these arrangements may not be enough for major disasters and losses but work to a satisfactory level for less severe events. Micro-insurance is considered to be a credible alternative. As per Mechler et al. [25] disaster micro-insurance has been implemented in developing countries with the aim of facilitating affordable life and health insurances and also covering the loss of small scale assets from natural disasters. Authors stated that the micro-insurance is seen by the disaster risk management community as part of a wider, integrated disaster risk management system including risk prevention, preparedness and risk transfer. However, according to authors [25], there is a limited number of micro-insurance cover against disaster risks in developing countries.

2.3 Insurance for Disaster

Deductibles can be considered as a well-established and effective means to encourage private loss migratory measures which mean the insurer has to bear a part of the damage as per this principle [26]. Further authors have stated that deductibles shall be linked to the risk of the insured. Hence, high-risk prone households or other insured objects shall have the strongest incentives for migratory actions. As per the authors [25], insurance only indemnifies any loss through pooling the risks in exchange for a premium and does not reduce the immediate impact of the disaster which means affected people get compensated from the contributions of the number of unaffected. Thus, receiving larger compensation than the premium. Authors [25] have also explained micro-insurance by accentuating the difference of micro-insurance from other types of insurance through the affordability of such insurances by low-income people. Furthermore, micro-insurance provides timely financial assistance following extreme-event shocks, it reduces the long-term consequences of disasters.

Thieken et al. [26] have proposed insurance companies encourage their insured in private mitigation activities. They have proposed to educate the policyholders on disaster mitigation activities and any reward system for them for adhering to rules and regulations which has been imposed to minimise the effect of natural disasters. According to Kreimer et al. [27], the concentration is now being shifted to preventing losses and providing safety nets, that is from the earlier emphasis of emergency relief and rehabilitation. Gurenko [22] has also accentuated the fact of international financial institutions and the disaster management community are now placing great emphasis on pre-disaster, proactive disaster planning to reduce and transfer risks.

2.4 Sri Lankan Disaster Management and Insurance Policy

Sri Lanka has undergone many major natural hazard-induced disasters in the recent past, such as drought cycles, floods and landslides, with the government facing a pattern of rising relief payments [2]. Thus, the government and streamlined non-government organisations provided relief for the causalities of such disasters [6]. The author [6] has highlighted that through financial assistance and rehabilitation programmes these institutes have succeeded to some extent in overcoming the situation. Nevertheless, the Disaster Management Act was enacted in 2005 to include appropriate immediate legal guidelines in order to efficiently handle all stages of a disaster and to strengthen the community's resilience and was subsequently updated into a national framework [2]. In addition, the authors claimed that the Disaster Management Centre (DMC) was also set up and currently DMC, which works under the Ministry of Disaster Management, set up a disaster management program in 2014 and intended to incorporate the Sendai System into disaster management in Sri Lanka.

In the past, National Disaster Relief Services Centre (NDRSC) released disaster relief directly to the appropriate government agencies for recovery and restoration activities [6]. As per the regulations, families to be eligible for relief on any widespread disaster even though being a causality must have a monthly income of less than LKR. 3000.00 for the whole family. Divisional Secretaries shall decide on the relief eligible families and collect provisions relevant to their relevant divisional secretariat. The NNDI policy was proposed as a Budget plan in 2016 to boost the country's economy and growth. This is to be done under the joint oversight of the Ministry of Disaster Management and the National Trust Fund for Insurance under the Ministry of Finance.

3 Research Method

A study of prior literature is important to recognize the gaps in current knowledge [28]. Hence, literature was collected from books, journal articles, industry reports, conference proceedings and from documents related to disaster, disaster management, disaster management in developed and developing countries, disaster management in Sri Lanka and insurance policy. Further, Kumar [29] stated that to achieve the desired objectives of a research study, it is necessary to identify the most appropriate research approach, strategy and techniques. The research approach can be discussed under three categories as a qualitative, quantitative and mixed approach [30]. As the study focuses on the issues in the existing NNDI policy, limited literature is available as the policy was introduced in 2016. When research requires the experience and different perspectives of the people, the ideal approach is the qualitative approach [31]. Further, through a qualitative approach, in-depth opinions and attitudes of the participants, experiences and behaviours can be observed while conducting the interviews with the participants [32]. Thus, to identify the current status of the NNDI policy, a qualitative approach was used. As the study followed the qualitative approach, ten (10) semi-structured interviews were conducted with the experts who have sound knowledge in disaster management and NNDI policy. Data gathered from semi-structured interviews were analysed using content analysis manually. Table 1 shows the profile of the respondents.

4 Analysis

4.1 Disasters in Sri Lanka

Sri Lanka, being situated in a path of two monsoons has resulted in adverse weather conditions which leads to several natural hazard-induced disasters. In the recent past decade, Sri Lanka faced several tragedies like landslides, floods, tsunami,

Table 1 Profile of the Respondent

Profession	Code	Years of experience
Assistant Manager in Insurance Regulatory Commission of Sri Lanka	E1	18
Kegalle District Secretary	E2	15
Scientists in the National Building Research Organisation (NBRO)	E3	7
Assistant Director in Disaster Management Centre (DMC)	E4	20
Engineer in National Housing Development Authority (NHDA)	E5	16
Chief Executive Officer (CEO) in the National Insurance Trust Fund (NITF)	E6	28
Senior Lecturer in Disaster Management	E7	13
Assistant Professor in Disaster Management	E8	18
Assistant General Manager in NITF	E9	12
Director in NDRSC	E10	21

storms, droughts and forest fires. Furthermore, respondent E4 said, "*when a natural phenomenon takes place continuously by creating damages to property and community, it leads to disasters. As an example, if we take the flood that took place in the Kolonnawa Divisional Secretariat in 2016, it created huge damages to the properties. Those property damages were categorised into five criteria depending on the extent of damage as, less than 10,000, 10,000–25,000, 25,000–250,000, 25,000–2,500,000 and above 2,500,000. Number of property damages in each criterion is, 56(2%), 112(4%), 2484(85%) and 279 (10%) respectively*".

Almost all the respondents highlighted that human activities in the environment have resulted in changes in the environment which has led to long-term disastrous situations. Moreover, respondents highlighted that as Sri Lanka is facing more landslides and floods frequently, the most common reasons for these disasters are continuous heavy rainfalls, lowland reclamation, forest clearance in hilly areas, sand mining in the river valleys, changes and blocks in waterways, use of mountain areas for construction activities in an improper way and water storing in highlands. Similarly, respondent E4 stressed, "*Aranayake landslide which took place in the Sri Lanka was basically due to the mismanagement of the land use by the humans has lead for the landslide in the long run*". When a disaster hits the country, it impacts the economy, social life and also the environment in an adverse manner. Impacts of disasters are mainly, destruction of harvest, food scarcity, the spread of epidemic diseases, destruction in biodiversity, loss of property and life, damages caused for infrastructure. Therefore, to bring back the daily lifestyle of the people after a disaster, it is necessary to have a proper system to compensate the needful victims. Thus, NNDI policy is considered as one of the ideal solutions to build back the lifestyle of the victims of a disaster.

4.2 Process of Disaster Evaluation and Compensation in Sri Lanka

Before compensating the victims of a disaster, it is necessary to evaluate the losses caused due to the disaster. Thus, interviewees were asked to explain the loss evaluation process in case of a disaster. Hence, respondent E2 said, "*When a disaster hits the country, several parties like National Council on Disaster Management (NCDM), Disaster Management Centre (DMC), National Building Research Organisation (NBRO), National Disaster Relief Centre (NDRC) which operated under the Ministry of Disaster Management (MDM) get together to compensate the victims of the disaster*". Before the introduction of NNDI policy in 2016, MDM used funds from the Treasury to compensate the victims of the natural disaster. Furthermore, respondent E9 said, "*Before 2016, in case of a natural disaster, victims whose income limit is up to Rs. 5,000.00 were eligible to receive compensation in a natural disaster. That means almost all the Samurdi beneficiaries were considered to receive the compensation*".

In a natural disaster, for a full house damage maximum payment, was up to Rs. 100,000.00 while for the partially damaged houses up to Rs. 50,000.00 were paid before the implementation of the NNDI policy. After 2016, NNDI policy is executed with the joint collaboration of MDM and National Insurance Trust Fund (NITF) and it is operated under the supervision of the Finance Ministry. Respondents E1, E4 and E8 highlighted that policy covers all the disasters except droughts and fire. Therefore, when a tragic disaster takes place in the country, in order to compensate the victims, the first damage assessment is being carried out by the district secretaries and Grama Niladari (government officials liaising with communities at a village level). Further, responded E7 stated, "*In the disaster situation, disaster management employees, stakeholders, divisional and district secretaries, Grama Niladari and ministries get together*".

To compensate the victims, LKR 250,000 is being paid in death and for property damage LKR 2,500,000 is being paid. Further, respondent E9 stated, "*Until the victims come back to their normal life style, weekly dry rations are being provided*". After quantifying the damage that needs to be paid for the victim, compensation is directly credited to their bank account. Before providing the claim to the victim, details of the victim is verified through the Identification of National Identity Card (NIC) number, claim form and through the ownership of the property. Once the details are verified, compensation is being paid for the victims as shown in Fig. 1. Furthermore, respondent E10 highlighted, "*Though compensation is provided for the victims, betterment is not covered through the NNDI policy*".

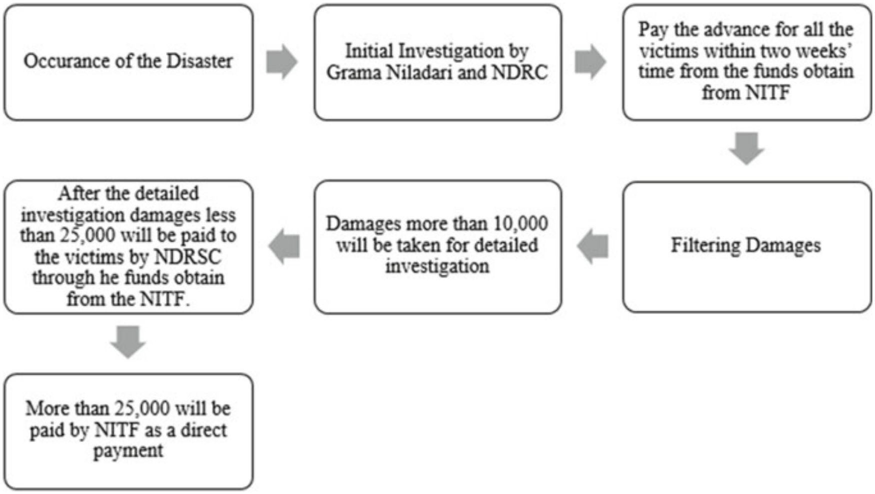

Fig. 1 Process of disaster evaluation and compensation in Sri Lanka

4.3 Issues and Challenges in the NNDI Policy

Though the NNDI policy was introduced in 2016 to compensate the victims of the disaster, there are drawbacks to the policy. Thus, interviewees were queried on "What are the issues and challenges in the NNDI policy?".

Although NNDI policy helps the victims of a disaster, respondents stated that there are issues and challenges that need to be addressed. One of the key challenges highlighted by the respondents is loss adjustment and claims. Respondent E5 said, "*Misguidance of the stakeholders in the process of loss adjustment and claims has resulted in issues in compensating the victims*". Furthermore, respondents stated that if the NITF do any changes in the claims by reducing the claim size, there is no way to communicate the change for the beneficiaries. Moreover, respondents also highlighted the issue of delay in processing the claim. Before the victims claim for their losses, it is required to carry out the damage assessment. When the assessment gets delayed, it ultimately results in a delay in the processing of the claims. In addition to that, respondents also highlighted the issue of insufficient staff. In a disaster, on behalf of the insurance, district secretaries take responsibility for assessing the damages. Along with the district secretaries, technical officers also get involved to assess the damage. Respondent E2 highlighted, "*due to the availability of limited number of technical officers, real assessment of the disaster faces difficulties and this has resulted in the delay in the claim process also*". When a claim is to be paid, the path is so long and people cannot wait. It is one of the major challenges. People cannot wait for a long period till the reconstruction take place and the greater value of insurance policy and the scheme is diminished by the delays of the operations of government structure.

Lack of guidelines on the claim process has also resulted in delays in claiming the compensation. Respondent E3 highlighted that the main reason for this is due to the insufficient understanding of the policy and the guideline is not clear for the stakeholders. Furthermore, respondents E2, E4 and E9 said that exposure towards the policy is also needed to be improved in the stakeholders. Further, the government has announced a system to resettle the identified families in high-risk areas through a Cabinet decision. Although the process takes some time, the real difficulty is in finding suitable land to resettle. To resettle people, land should be in a safer location and it needs to be certified by NBRO. But the major problem is to find suitable land. Since the people in these areas, nearly 15,000 families, they started their dwellings from very past. They have been living in these areas for two to three generations. That is their outright property. Similarly, respondent E2 added, "*because of climate changes we are receiving these unusual weather changes which we have not seen previously. Until government give a solution we have to look after the people in high-risk areas*".

In Kegalle area, lands that are identified as the high-risk areas are their cultivated land. There is vegetation like tea, cardamom and cloves in these areas. If those lands are acquired, then the people living in those areas will be facing a lot of problems with their livelihood. Therefore, as a policy, the acquisition of their lands will not take place. But with the help of NBRO, the government is trying not to settle anybody in a risky area which is identified by NBRO. But this process will take some time. In addition to that, NBRO has introduced a very sophisticated system with the community which Ministry of Disaster Management and other technical agencies were not being able to introduce. Further, NBRO has community-based early warning system. This early warning system has helped to reduce the damages to life. But this early warning system is available only for landslides and early warnings for floods are issued by the Irrigation Department. Respondent E7 stressed that it is important to introduce an early warning system for floods and other disasters also.

Moreover, the lack of knowledge on indemnity base assessment of DS staff is also identified as a challenge faced in compensating the victims through the NNDI policy. Due to the lack of knowledge in the DS staff, has resulted in issues like over-estimation and under-estimation of the claims. Similarly, respondents highlighted that due to the issues in record-keeping, wrong information about the damage is considered in compensating the victims and also victims try to maximise the benefits than covering the damage. Furthermore, omission of Built back better concept from the policy was also identified as an issue through the study. Respondent E6 said, "*if a house had been affected by a high wind situation, repairing should be done with some resilient features to withstand for any possible disaster. If you do not repair with resilient features and if another disaster take place in the same location again, then another claim can be recorded in next time. Thus, if the government objective is to make country's housing stock a resilient housing stock, then build better concept to this insurance policy is a must*". Further, having a proper valuation method for all the properties in high-risk areas will help to reduce the gap after a disaster. Respondent E3 highlighted, "*people try to maximise the insurance because those who are not affected by the flood submit and demand that they have a claimant.*

They continuously wrote to the president and prime minister and even asked for the 0.5 million compensation. In 2016 and 2017, there were issues like that".

People tried to maximise benefits rather than doing the compensation for the actual damage. Therefore, collecting the proper data is the challenging part. Creation of a database with proper details is the challenge. If a proper database can be created, then the estimation of resilience and costing part will be easy. An additional burden for the government is also another challenge highlighted by the respondents. In a disaster situation, the allocated amount for compensation is 2.5 billion. Though the amount is allocated as 2.5 billion if the requirements are higher than the allocated amount, then payments are carried up to 4.5 billion. Further, respondent E4 said that in the process of processing the claims, cost of officers, fuel and admin costs are considered as an additional burden which the government has to bear. Respondent E-6 stated, "*We have to have some sort of matching with the gap between the resettlement and the reconstruction*".

Reconstruction is the easiest and fastest way to reconstruct houses. Resettlement takes a lot of time and resettlement decisions are taken based on the risk associated with the location. Respondent E1 highlighted, "*There are houses without a single crack, but the location is highly vulnerable for a landslide. In such instance, it is proposed to resettle those houses*". Although the reconstruction part is addressed in the policy, the extent of focus on the reconstruction is lesser than resettlement. When the resettlement of the people take place, it is necessary to look into Built back better concept and resilient houses. The key part is that resilient features need to be added. Adding resilient features is betterment. So resilient features have to be covered from some financial resources but not from the policy since betterment is not covered from the policy. Insurance policy is based on exact indemnity value. If the risk factor is reduced, then the policy can be improved and solutions and compensations can be increased in future. Further, structural damages can be reduced by construction with resilient features.

Moreover, unavailability of monitoring mechanism to monitor the use of insurance claims is identified as another issue in the NNDI policy. In any insurance scheme, there is a monitoring part. Respondent E1 said, "*If our vehicle gets into an accident and when we are going to claim the insurance, then we need to show that we have properly repaired the vehicle with approved claims. But when it comes to NNDI policy, nobody knows how people used their claims. Whether they have actually repaired their house damages or not*". Therefore, such situation may lead to misuse of insurance programmes and some people can reclaim the damage in another disaster also. Thus, there should be a proper monitoring mechanism to monitor the use of insurance claims. Hence, issues and challenges in the NNDI policy can be summarised as shown in Table 2.

Table 2 Issues and challenges in NNDI policy

Issue and challenges	E1	E2	E3	E4	E5	E6	E7	E8	E9	E10
Loss adjustment and claim management	√	√	√	√	√	√	√	√	√	√
Delays in processing claims	√	√	√	√	√	√	√	√	√	√
Insufficient staff	√	√	√	√	√	√	√	√	√	√
Omission of built back better concept from the scheme	√		√	√		√	√	√		√
Lack of clear guidance on the claim process	√	√	√	√	√				√	√
Lack of knowledge on indemnity base assessment of DS staff			√	√	√	√		√	√	√
Inadequate record-keeping	√	√	√	√	√		√	√	√	
An additional burden for the government		√	√	√		√	√		√	√
Unavailability of monitoring mechanism	√		√		√		√		√	√

4.4 Conclusion

When a disaster hits a country, harmful impacts are affected by the people in the society. Therefore, to overcome the adverse consequences of disasters, migratory actions are being followed. As an initial step, compensation is being provided for the victims of the disasters to cover up their losses. When considering Sri Lanka, over the recent past years the country was affected by several natural hazard-induced disasters like Tsunami, landslides, floods and cyclones. Thus, the government took the initiation in introducing the NNDI policy with the aim of, improving the development and economy of the country. Through the policy, compensation is being provided to the victims—over and above the relief previously available to affected households. Being one of the first of its kind as a national-level macro-insurance policy providing coverage for all the properties in a country against natural hazard-induced disasters, the case of NNDIP in Sri Lanka can be considered as a good opportunity to explore the potential for such an approach. It can be seen that many of the households affected by a disaster event during the time the scheme was in operation have benefitted from the policy. Though compensation is provided, there are issues and challenges such as loss adjustment and claim management, delay in processing claim, insufficient staff, omission of Built back better concept from the scheme, lack of clear guidance on the claim process and unavailability of monitoring mechanism to monitor the use of insurance claims. Hence, for the successful implementation of the policy, these issues need to be addressed.

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Hydrological Analysis for Flood Forecasting at Sg Golok River Basin Malaysia

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Abstract Large areas of Malaysia repeatedly suffer from prolonged, significant floods and in past, several flood-related disasters happened due to heavy rainfall in the Golok River Basin at the Kelantan state of Malaysia. Therefore, in this research, the hydrological analysis is being conducted in that area and five extreme flood disasters are chosen for validating the analysis. The preliminary event-based and gauge-based analysis is shown in this research for validation. The results showed that during the disasters in 2008, 2009, 2014, 2016, and 2017 shows that this hydrological analysis will be a significant element for the National Flood Forecasting and Warning System (NaFFWS) program for Malaysia.

Keywords NaFFWS · Flood forecasting · Hydrological analysis · Sg Golok

1 Introduction

Floods are chronic natural disasters with potentially very serious consequences. Weather events that caused many fatalities over the past decade have perpetuated the notion that, whether due to global warming or not, floods are becoming worse, more widespread, and more frequent [1–3]. Therefore, flood warning became a key research area in flood management. This means that previous methods of detailed interpretation of predictions from standardized sites will no longer be sufficient [4–6]. Although "the heart of any flow forecast system is a hydrological model", water modeling is one of the most important factors on which the effectiveness and efficiency of a flooded alignment and warning system be contingent [7].

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A flood forecasting system will ultimately help on improving the effectiveness of the flood mitigation system. This adds to the importance of flood modeling so that flood forecasts provide a warning in stormy conditions to reduce human losses and property damage. However, rainfall data with good temporal and spatial resolution and accuracy are required for a better hydrological model [8, 9]. Besides the rain details must also be available in real-time. A flood warning is a non-structural method that is effective and cost-effective to reduce the negative effects of flooding [10, 11]. A national agency such as the Department of Irrigation and Drainage (DID) of Malaysia provides flood forecasting services and warnings. DID introduces a system based on the phased implementation of the system, which brings together the new National Flood Forecasting and Warning System (NaFFWS) for its key river basins [12].

The "NaFFWS Phase 1" plan was finalized in 2017. The phase was developed by using a very popular integrated catchment modeling (ICM) software named InfoWorks ICM for hydrological and hydrodynamic models and ICMLive shell for flood forecasting. The main river reaches the main streams as a 1-D boundary, and the floodplain associated with these rivers must be used with a 2-D mesh. With appropriate rainfall details, the ICM model can determine river flow including water level, water depth, and velocity in the upper layer. However, an additional tool that can upload the real-time weather data or active alerts automatically by analyzing the weather forecasts. Therefore, the ICMLive system is required.

The main objective of this research is to boost the NaFFWS performance by introducing ICMLive support. In this way, flood forecasting can be done using the national network data, the telemetry and radar data, and most importantly the rainfall forecast data. This paper will describe the pilot case that covers the key river basins on the east coast of Malaysia named as Sungai Golok River Basin of the Kelantan state. The study area is important as it was directly affected by the northeast monsoon.

2 Methodology

Figure 1 illustrates the map of DID rainfall, water level, and streamflow station that are owned by DID in which the data extracted from these stations will be used for hydrological analysis in this study.

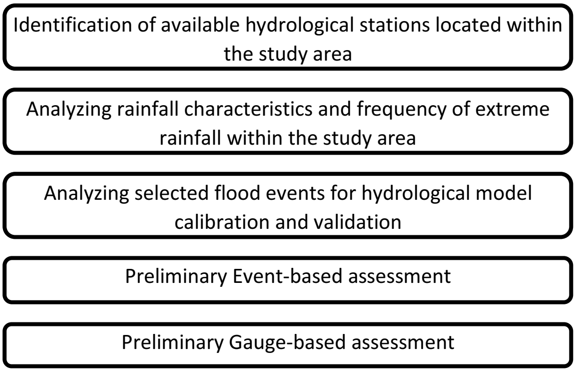
The steps of doing the hydrological analysis are shown in Fig. 2.

The first step was by identifying the rainfall stations in the Golok River Basin. There are 12 rainfall stations operated by DID, which are in good condition and have been selected for hydrological analysis in Golok River Basin. The average total annual basin rainfall/areal rainfall in Golok River Basin is illustrated in Fig. 3. It is observed that Golok River Basin receives about 3200 mm of rainfall annually.

The 2nd step of this research is analyzing the rainfall characteristics using the rainfall double mass curve analysis process. It is noticed from the plot of each station (as shown in Fig. 4) in Golok River Basin that the selected stations are portraying good consistency and quality as most of the plots are having a slope value of close to one. In this research, the Intensity–Duration–Frequency (IDF) curves are used which

Fig. 1 DID rainfall, streamflow, and water level station in Golok River Basin

Fig. 2 Hydrological analysis steps for Golok River Basin



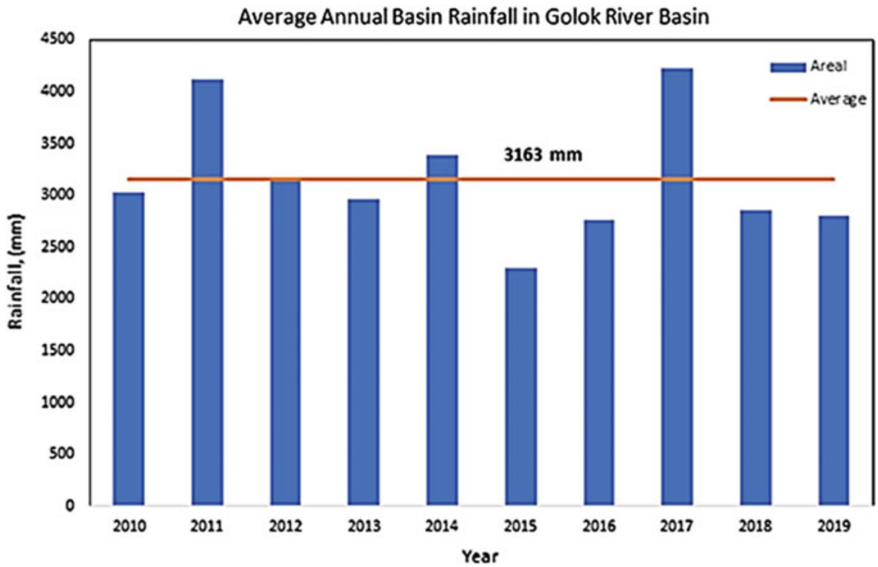


Fig. 3 Average total annual basin rainfall in Golok River Basin

describe the relationship between rainfall intensity/magnitude, rainfall duration, and return period (or its inverse, probability of exceedance). IDF curves are commonly used in the design of hydrologic, hydraulic, and water resources systems. Apart from that, it is also used as a reference to identify the magnitude of rainfall amount that induced floods. IDF curves are obtained through frequency analysis of rainfall data collected in the rainfall stations of different rainfall intervals.

The rainfall frequency in this study was conducted by extracting the annual maximum rainfall amounts of different rainfall intervals from the stations located within the study area. These observed annual maximum rainfall amounts were fitted to theoretical Extreme Value (EV) Type 1 distribution (Gumbel distribution) for estimating the corresponding exceedance probabilities of particular rainfall amounts. The IDF curves are only computed for stations with long and consistent rainfall records as only IDF curves computed from long and consistent rainfall records can reflect the actual climatic condition of the study area.

Then in this research, five different extreme flood events are selected for hydrological model calibration and validation. The flood events are the 2008, 2009, 2014, 2016, and 2017 floods. In this research flood events in Kelantan state is being selected to show the significance of the hydrological analysis of the Golok River Basin. The flood events and their consequences are shown in Table 1. There are quite a few floods are reported by DID that due to heavy rainfall in Golok River Basin. The latest disastrous flood happened on 31 December 2016 and it has caused the water level in Sungai Golok at Kampung Jenob to exceed the designated danger level. Continuous rainfall warning code had been issued by MMD for the flood on 31 December 2016. The consequences of the flood in 2017 are summarized in Table 1

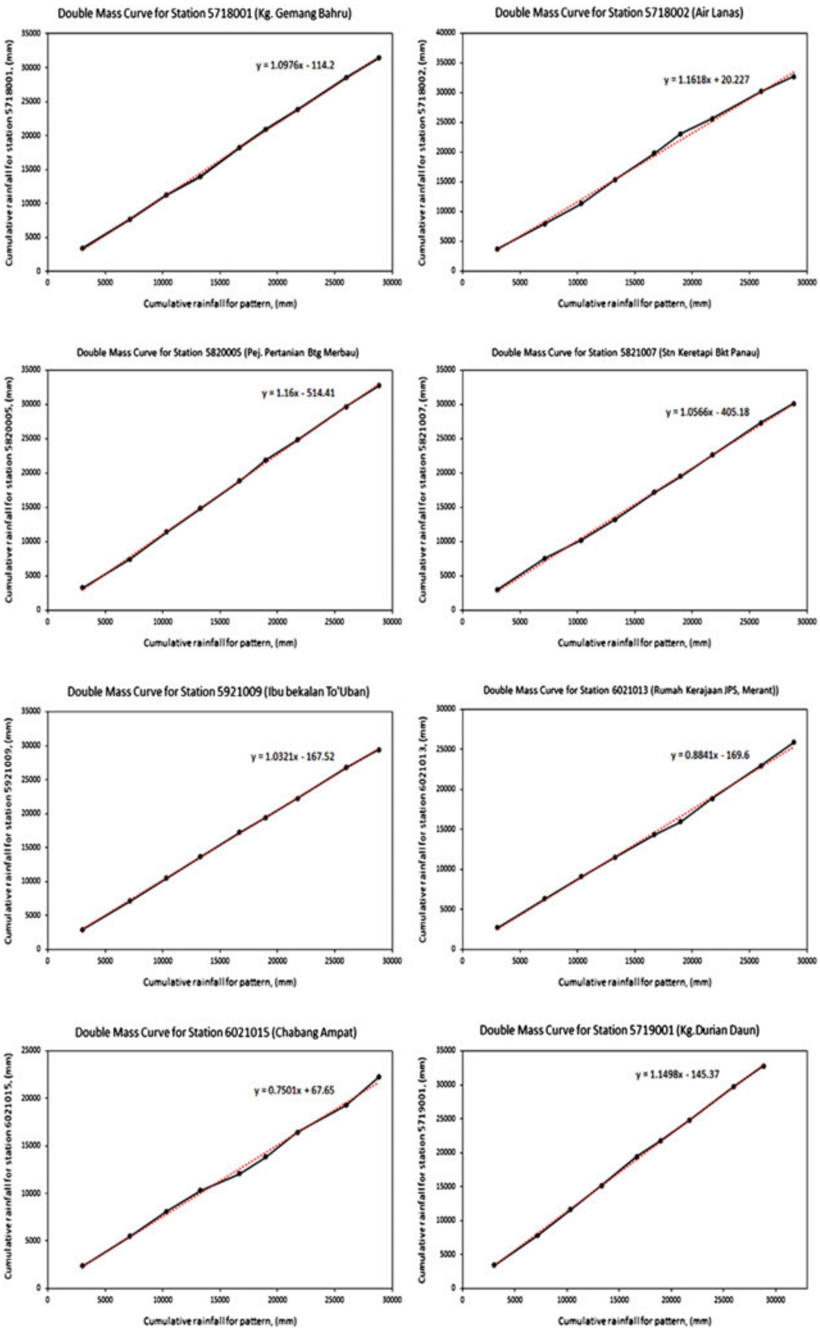


Fig. 4 Double mass curve computed for selected stations in Golok River Basin

Table 1 Consequences of flood in 2017 at Golok River Basin

Year	Inundated area	Flood depth	Evacuation (ppl)
2017	Kg. Muring	0.3–0.9	–
	Kg. Padang Kijang	0.3–1.8	27
2016	Kg. Siram, Kg. Pade Pak Atap, Bukit Lata, Kg Tokdeh, Kg Lachang and Tersang	0.1–0.3	
2014	Kota Bahru, Kuala Krai, Machang, Pasir Mas, Pasir Puteh, Tanah Merah, Tumpat	0.5–7.0 m	19,445 (4 death)
2009	Pasir Mas	1–1.5 m	2940
	Tumpat	0.6–1.8 m	1088
2008	Pasir Mas	0.5–1.5 m	405

and it is being shown that flood depth reaches up to 1.8 m. Another flood in 2016 has caused the water level in Golok River at Rantau Panjang to exceed the designated danger level. Thunderstorm and heavy raining warning code had been issued by MMD for the flood on 20 December 2016. In 2014 the most disastrous flood happened and the orange heavy rainfall warning code had been issued by MMD for the flood on 15 December 2014. In 2009 the continuous heavy downpours had led to the water level in Sungai Golok rose rapidly and it has exceeded the designated danger level in Rantau Panjang by 0.78 m. Red heavy rainfall danger code had been issued by MMD for the flood on 6 November 2009. The heaviest rainfall events were observed on 28 and 29 November in 2008. The observed water level exceeded the designated danger level in Rantau Panjang by 1.26 m that year. The orange heavy rainfall warning code had been issued by MMD for the flood on 30 Nov. 2008.

Finally, the event and gauged-based analysis is conducted in this research. The selected flood events will be used for calibration and validation of the model constructed in this study for flood forecasting purposes. Thus, the efficiency and functionality of the model depend greatly on the quality of input data such as rainfall data used for simulation as well as water level and streamflow flow used for calibration and validation of the simulated water level and streamflow data. The event-based assessment was carried out to assess the quality of the rainfall data recorded in each rainfall station during the flood events selected for simulation.

The accuracy and efficiency of the model is greatly depending on the quality and errors in the input data. Apart from rainfall data as input data, the water level data recorded in the streamflow station are usually used for the estimation of parameters and calibrating the simulated results. The hourly water level data recorded in each streamflow station during the selected flood events are assessed. It will be checked whether the water level data during the flood events are abnormal or missing. On top of that, the observed water level data is also assessed against the designated warning level and danger level.

3 Results and Discussion

Figures 5 and 6 illustrate the IDF curves derived for station Air Lanas (5,718,002) and station Kg Durian Daun (5,719,001) in the Golok River Basin for rainfall intervals from 1-h to 120-h (5 days).

The research also generates the rainfall time series of flood events in 2017, 2008, and 2009. The magnitude and ARI of the maximum 1-day, 2-day, and 3-day for 2017 floods are depicted in Figure 7 and the rainfall spatial distribution map for 1-day, 2-day, and 3-day maximum rainfall during those flood events is illustrated in Fig. 8.

The Preliminary Event-Based Assessment is done in this research. The hourly rainfall data recorded in the respective rainfall station during the selected flood event was compared to the 99% confidence interval of the rainfall data recorded in neighboring rainfall stations at an identical time frame. The 99% confidence interval of the

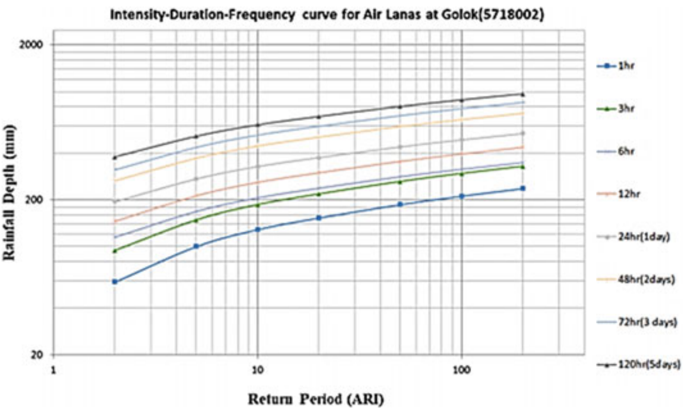


Fig. 5 IDF for station Air Lanas (5,718,002)

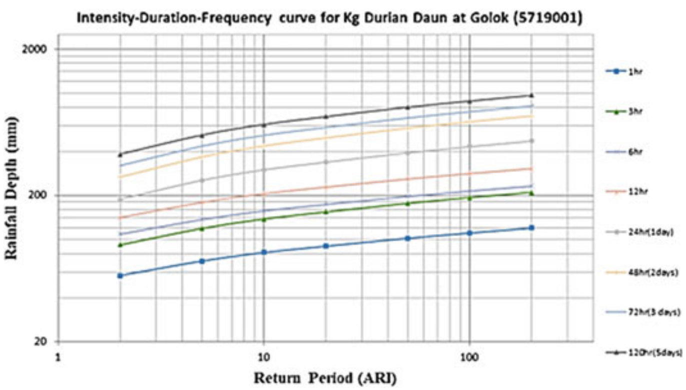


Fig. 6 IDF for station Kg. Durian Daun (5,719,001)

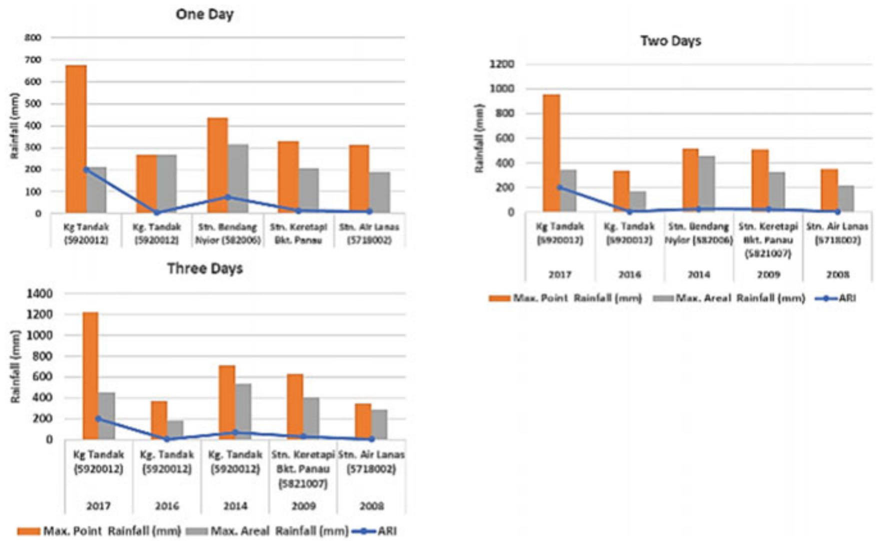


Fig. 7 ARI and maximum point rainfall for floods in Golok River Basin

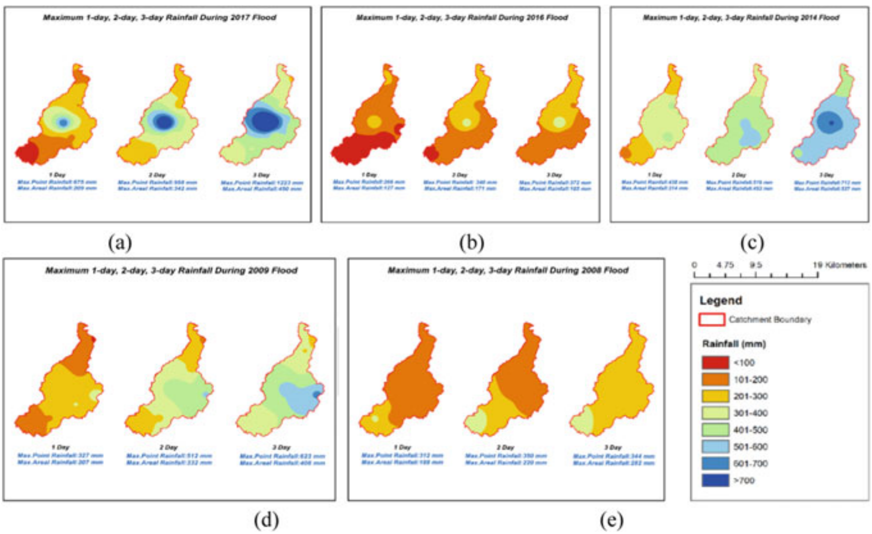


Fig. 8 Rainfall spatial distribution map for 1-day, 2-day, 3-day maximum rainfall during flood events in the Golok River Basin

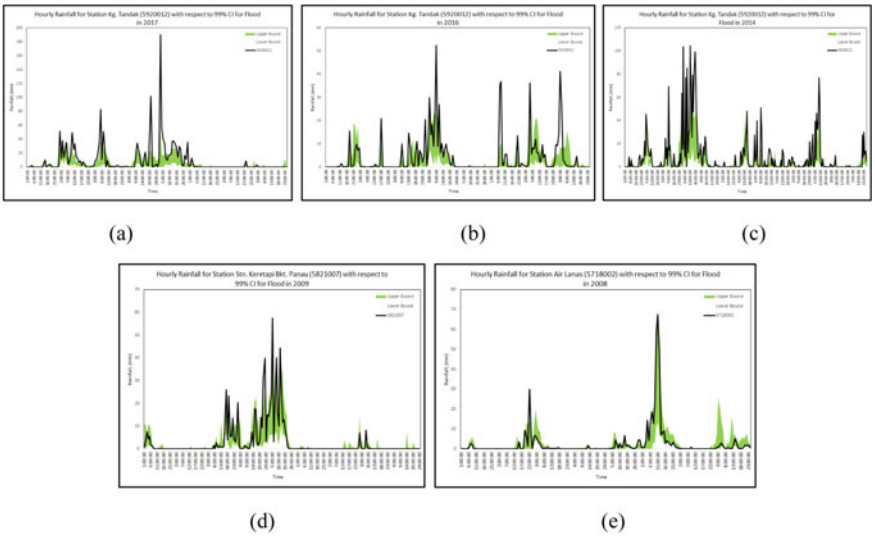


Fig. 9 Results of event-based assessment for hourly rainfall recorded at different stations of the Golok River Basin

rainfall data from neighboring rainfall stations represents the rainfall trend/pattern of the study area at a particular duration. If the rainfall data recorded in a station violates the rainfall pattern observed from a neighboring rainfall station, in which the observed rainfall data locate beyond the range of 99% confidence interval, then it is suspected that there may be errors for the observed rainfall data in that particular station and correction may be required for that observed rainfall data. The modeler may use the data of this event-based assessment to help them to correct the rainfall input data if it is necessary. According to Fig. 9, it is being shown that mostly the rainfall data recorded in each rainfall station during the floods in 2008, 2009, 2014, 2016, and 2017 is in good condition and no large variation is observed for any rainfall station when compared to the rainfall pattern of neighboring stations. However, the modeler may correct the rainfall amount (as long as it follows the rainfall pattern of neighboring stations) according to the requirements of the constructed model if it is necessary.

The preliminary Gauge-based Assessment was also accomplished in this research to validate the rainfall analysis. Figure 10 illustrates the results of gauge-based assessment for hourly water level data recorded at different stations during the flood events occurrences. It is being shown that the station Jenob (5,818,401) and the station Rantau Panjang (6,019,411) from 31 December 2016 to 8 January 2017 during a flood event in 2017 exceeded the designated warning level and danger level, which is validating to the selected flood event in 2017. Also, in the Figure, the station Jenob (5,818,401) and station Rantau Panjang (6,019,411) from 17 to 25 December 2016 during a flood event in 2016 shows the exceedance of water level, whereas the station Jenob (5,818,401) and station Rantau Panjang (6,019,411) from 16 to 29

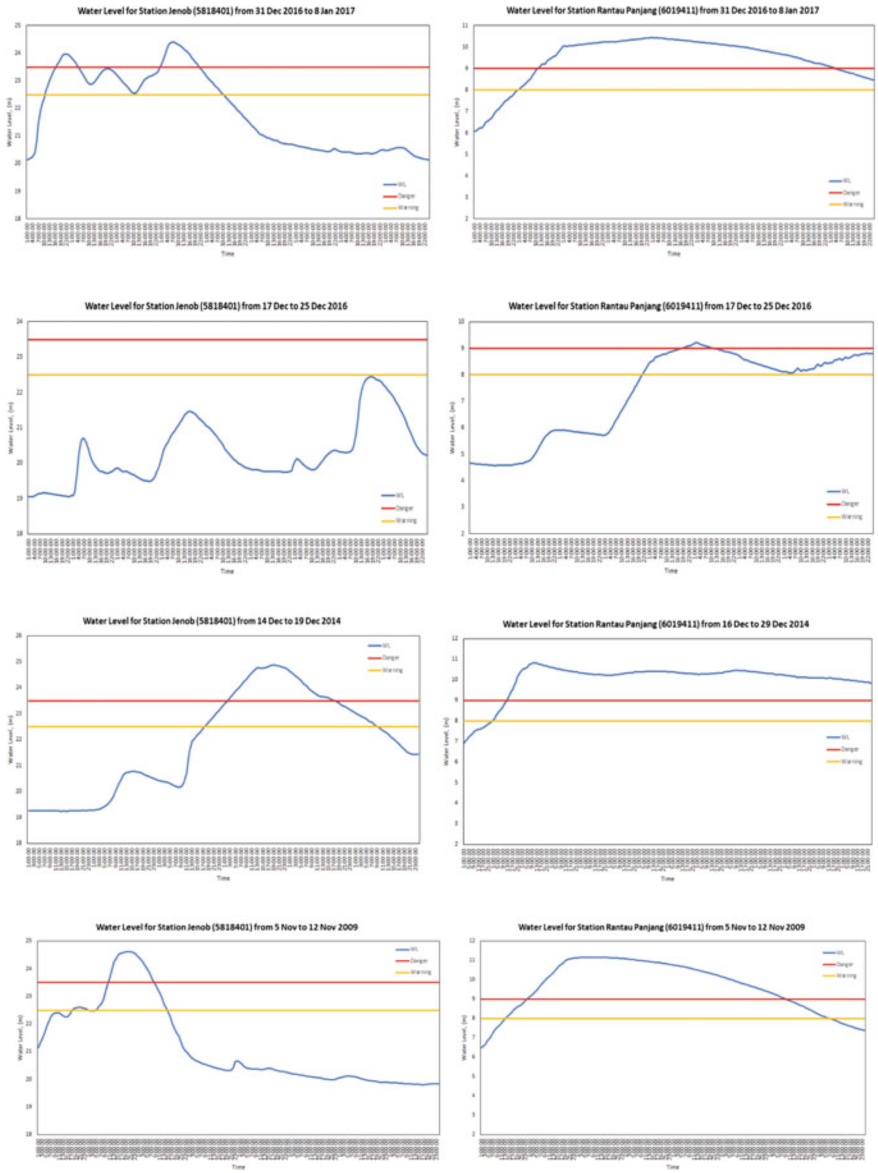


Fig. 10 Results of gauge-based assessment for hourly water level recorded during flood events in the Golok River Basin

December during a flood event in 2014 proves the water level is exceeded. In the 2008 and 2009 flood event the stations that show dangerous water levels are station Jenob (5,818,401) and station Rantau Panjang (6,019,411) from 27 November to 5 December during a flood event in 2008 and station Jenob (5,818,401) and station Rantau Panjang (6,019,411) from 5 November to 12 December during a flood event in 2009 respectively.

4 Conclusion

An innovative and new approach to provide a flood forecasting and warning service to the public by the Malaysian Government's Department of Irrigation and Drainage is launched as National Flood Forecasting and Warning System (NaFFWS) program. In this research, the hydrological analysis for the NaFWWS program is described to prevent one of the deadly disasters in Malaysia, floods. The research shows the steps related to the hydrological analysis and compared the results with the most five devastating floods that occurred due to the Golok River Basin in Malaysia. In 2008, 2009, 2014, 2016, and 2017 there are severe floods occurred and the hydrological analysis is validated using the data related to those disasters. The gauge-based assessment for hourly water level recorded during flood events in the Golok River Basin proved that few stations are overtopped during the flood and the event-based assessments, as well as the spatial rainfall distribution, are shown in this research. The research will be an important guideline to build the NaFFWS system in the future.

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Developing the Flood Risk Matrix for Impact-Based Forecasting in Kelantan River Basin, Malaysia

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Abstract Impact-based forecasting (IBF) is a relatively new concept to implement in Malaysia. The catastrophic effects of natural disasters such as floods can be minimized if an early forecasting system is being developed. Also, by using the IBF concept, people can forecast the devastating impact of natural disasters such as flood, which is very prone to happen in Malaysia. In this research, one of the most dangerous flood events in 2014 at Kelantan state in Malaysia is chosen as a case study area and the developed flood risk matrix (FRM) is validated. The FRM was developed by determining the scoring value by integrating receptors' impact with 16 flood scenarios and the flood depth as weightage. The results showed that using the IBF concept and the impact threshold values, the ArcGIS based FRM map can predict the impact in the nearby area of the Kelantan river basin. This FRM matrix will be generated in other areas and help produce the flood guidance statements for Malaysia.

Keywords IBF · Flood forecasting · Kelantan river basin · Flood risk matrix

1 Introduction

Many floods are happening in Malaysia and floods due to potential adverse consequences in the crisis scenario. This is understood in compliance with Article 3 of the Crisis Management Act of 26 April 2007 as "a situation which adversely affects the level of safety of people, the property of significant size or the atmosphere, resulting

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in significant restrictions on the functioning of the related public administration bodies due to the inadequacy of the forces and possessed means" [1]. According to a famous newspaper in Malaysia named Bernama Dec 2019, continuous rain-triggered 18 temporary flood evacuation centres in Kelantan accommodate 456 evacuees from 119 families. 149 evacuees from 40 families were registered in Tanah Merah, while 68 evacuees from 20 families were registered in Pasir Mas and both districts currently have two evacuation centres available to respond to flood victims. In Kusial, Tanah Merah, the water level of Sungai Kelantan also showed rising waters with a 14.94 m reading above the 14 m warning level. Four sites, meanwhile, were at the alert stage, namely Sungai Galas in Dabong, Kuala Krai as well as Limau Kasturi, Gua Musang, with readings of 32.75 m and 57.23 m respectively, while Sungai Pergau registered a water level of 72.13 m in Air Bol, Jeli and in Air Bol, Jeli. The water level of rivers in seven locations in Kelantan has been slowly rising, with two heading beyond the risk level [2].

The early warning of any natural hazard and disaster reduce the impact significantly. Likewise, flood-related disasters can be forecasted and the adverse impact can be calculated early [3–6]. Therefore, The World Meteorological Organization (WMO), conveying the outcomes of the Third UN World Conference held in Sendai [7], has highlighted the need for impact-based forecasting and warnings (IBFW) services to bridge the gaps hindering effective EWSs [6]. Impact-Based-Forecasting (IBF) is a method that gathers and incorporates information to estimate the impact of impending disasters on disadvantaged people living in areas subject to such disasters [8]. The IBF concept has already been introduced in a very recent article by Sidek et al. [9]. When communities can adapt proactively to a catastrophe through early warning and early intervention, injury, distress and the cost of emergency assistance can decrease. There are three crucial components, i.e. understanding risk, identifying impact and forecasting trigger value. It is essential to carry out a preliminary flood risk assessment for the production of flood risk maps, considering the process of estimating the value of possible flood damages in individual land-use groups. The paper proposes using matrix methods for the analysis and assessment of flood risk under the applicable legislation. The flood risk matrix will eventually support the IBF concept and the results will be validated using the flood disaster that happened at Kelantan in 2014.

2 Study Area and Data Collection

Sungai Kelantan river basin is located on the Northeast coast of Peninsular Malaysia. The catchment is 11,900 km^2, with the length of its catchment being approximately 248 km and the maximum width reaches 140 km. Sungai Kelantan is the main and largest river in Kelantan state and divided into several rivers; Sungai Galas, Lebir, Neggiri and Pergau. Sungai Kelantan flows northward, from upstream to downstream area and passing through Kuala Krai, Tanah Merah, Pasir Mas and Kota Bharu before blending with the South China sea. Sub basins in the Kelantan river basin are shown in

Fig. 1 Kelantan river basin

Fig. 1. Nearly each Northeast monsoon season that occurs annually results in flooding on the Sungai Kelantan catchment area. This is due to the Northeast monsoon that also known as the wet season, carrying heavy rainfall. This monsoon season contributes to the high annual rainfall (2500 mm) of the Sungai Kelantan catchment, usually from mid-October to mid-January each year.

The data required in this study was supplied by several government agencies that collaborate in this study. The data used in this study involved the Digital Elevation Model (DEM), Flood Hazard Map, soil, land use and road and railway data supplied by the Malaysian Department of Irrigation Drainage. The Malaysian Department of Statistics supplied other data such as population data. In contrast, other data such as evacuation centres, utilities, agricultural area and transportation infrastructure were provided by National Disaster Management Agency (NADMA), Ministry of Energy and Natural Resources, Malaysian Department of Agriculture and Ministry of Transport, respectively. This study involved seven (7) receptors; agriculture, housing and properties, population, public facilities, road and railway, transportation infrastructure and utilities. The component of each receptor is shown in Table 1.

As a data preparation, these data are overlaid with each other among their mutual receptors for further process. Then they will be used for further analysis that will be explained further in the next section.

Table 1 Receptors and their elements for impact-based forecasting study

Receptors	Element
Agriculture	Paddy fields Rubber estates Oil Palms Coconut plantation areas Other plantation
Housing and properties	Houses Villages Industry buildings
Population	People/residents
Public facilities	Hospitals and clinics Schools Fire and rescue station Police station Halls Government office, Etc
Road and railway	Road Railways Expressway
Transportation infrastructure	Railway station Bridges Airports Jetties
Utilities	Electricity infrastructure Dam Petrol station Telco towers and infrastructure

3 Research Methodology

Flood Risk Matric (FRM) is the final product of an impact-based forecasting study. This FRM is in a 1 km × 1 km grid. Collected data are grouped in a respective grid and the total number of each receptor in each grid was calculated. The main objective is to estimate the level of impact of receptors in each grid. Figure 2 summarizes the Flood Risk Matrix (FRM) process to forecast the impact of the flood. As mentioned in the previous section, data preparation grouped all elements into their main receptor category. Then, the grid was overlaid into each receptor and intersected spatially for statistical analysis. Grid-based statistical analysis was applied to each receptor to count each receptor's total number in an individual grid.

Each receptor's total count number was then inferred to the impact threshold developed to score the impact into four levels; minimal, minor, significant and severe. Table 2 shows the impact threshold developed by the discussion with related agencies and departments according to previous flood events.

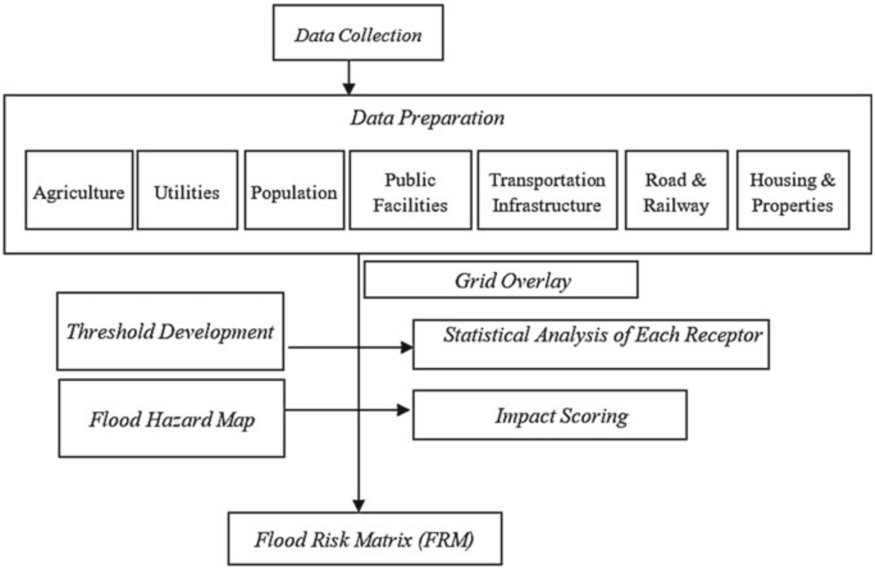


Fig. 2 Flood risk matrix development framework

Table 2 1 km × 1 km grid impact threshold

1 km^2 grid impact threshold				
Receptors	Impact level			
	Minimal	Minor	Significant	Severe
Agriculture (area percentage)	<20	20–50	50–80	>80
Housing and properties (number)	<10	20	50	>100
Population (number)	0	1–10	11–100	>100
Public facilities (number)	0	1	2	>3
Road and railway (km)	0–0.2	0.2–0.5	0.5–2.0	>2
Transportation infrastructure (number)	0	1	2–3	≥4
Utilities (number)	0–2	3–6	7–8	>8

Table 2 shows how the impact score of each receptor was determined. The agricultural area was assigned in a grid and the percentage of area covered with agricultural was determined and the higher the percentage of the agricultural area in a grid contributes to a higher score for impact level. This is contrary to other receptors such as housing and properties, population, public facilities, transportation infrastructure and utilities that count the number of receptors in one grid to estimate the impact level. Road and railway impact, on the other hand, were estimated by their length in one grid.

Table 3 Scoring matrices of flood and rainfall likelihood

Final scoring	Rainfall likelihood	Likelihood percentage	Tier	Impact category	Impact colour
0–2	Very low	<20	0	Minimal	Green
3–5	Low	20–40	1	Minor	Yellow
6–8	Medium	40–60	2	Significant	Orange
9–21	High	>60	3	Severe	Red

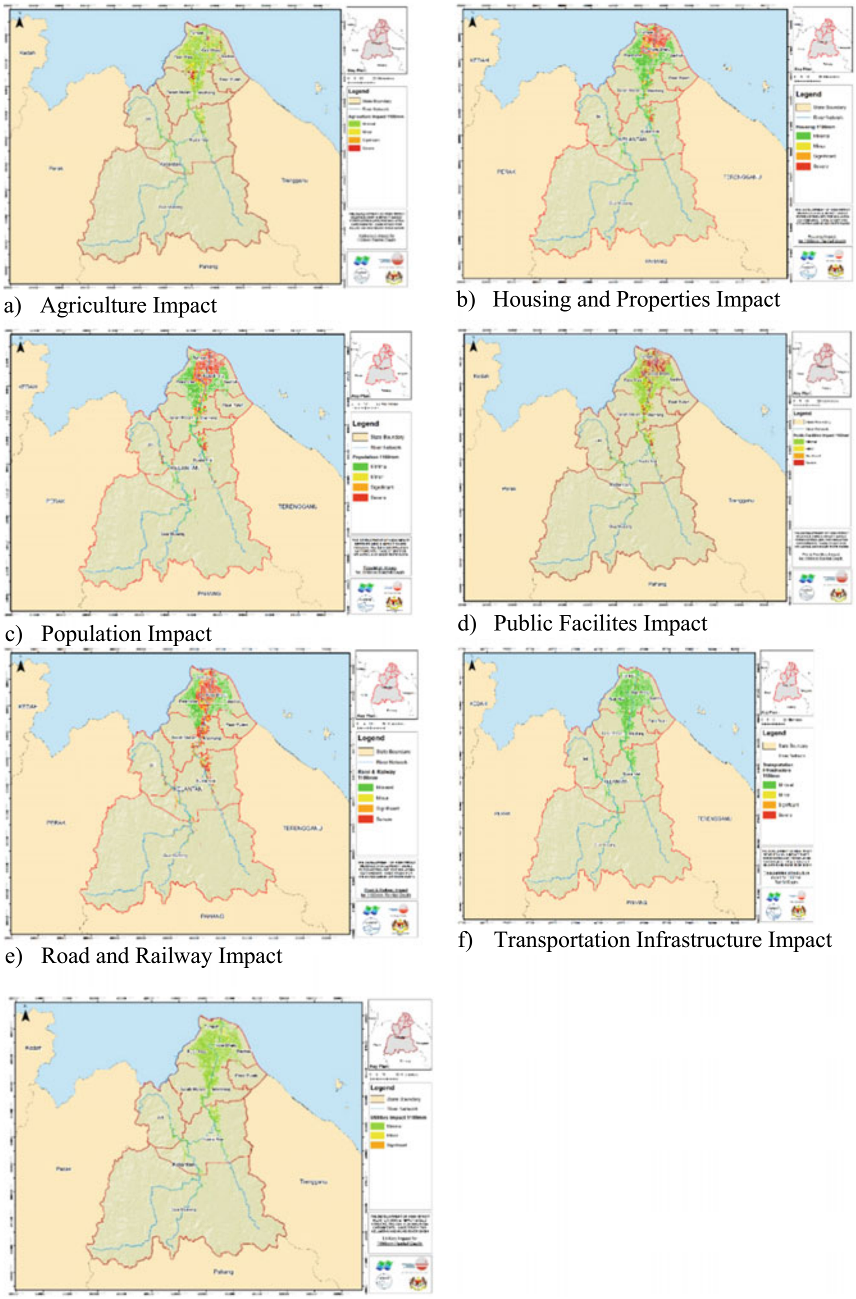
Then, each receptor's score was integrated spatially using the flood depth to estimate each receptor's impact severity. This process produces the impact score in one grid that then will be classified based on scoring matrices. These matrices then will be integrated further with the rainfall forecast event and then produced the Flood Risk Matrix (FRM). Table 3 summarizes the scoring matrices developed in this study.

4 Results and Discussions

4.1 Receptor's Impact by Impact Threshold

An essential feature of effective flood warning dissemination, particularly to the general public, is the use of receptors itself where early warning systems are well understood and effective response actions based on the local communities' preparedness. Figure 3a–g presents the 1 km cell for the seven receptors after the event's refinement based on the impact threshold in Table 2, where the maximum of all criteria is also included.

Figure 3a shows the impact of agriculture and the coverage area is dominated by a mixture of agriculture and seems no severe impact on that particular area. Based on the impact threshold for housing and properties, the result shows that the Kota Bahru area is more highly affected because the area is more densely populated than other districts. However, the population's impact is the same as housing and properties as these two parameters are connected. Besides, Kota Bahru is the capital state of Kelantan and the population density of the town is highly dense as public facilities impact is more severe the downstream where a large number of populations will be affected during heavy rain and flood events. Road and railway receptors are some of the receptors that have a significant impact on the threshold. Previously, the length of road and railway is determined directly from the statistical analysis made in ArcGIS 10.0 software. The maximum length in one grid cell carries a summation of length; 16 km. However, the minimum of 2-m road length with at least 1.2-m flood depth had been considered as severely impacted. This is because the network that connects people for help and mobility of victims was affected and hindered the rescue process. As it depends and there is a chance of affecting people's lives, the numbers need to be reduced to allow emergency responders to react precisely in an appropriate manner.



a) Agriculture Impact

b) Housing and Properties Impact

c) Population Impact

d) Public Facilites Impact

e) Road and Railway Impact

f) Transportation Infrastructure Impact

g) Utility Impact

Fig. 3 **a**–**g** Receptors impact for Kelantan flood risk matrix

The red area colour is being broadened to Kota Bahru's side resulted in the change number of thresholds. Kota Bahru area is considered the most developed city among Kelantan states. Most of the development infrastructure, building, road, the railway is centralized in Kota Bahru. The extension of the green colour upstream of Kelantan can be seen as the threshold had been reduced and space is given for the short length to be seen in the map. Transportation Infrastructure threshold impact has been identified as a critical point, whereas it includes jetty, terminal bus, airport, etc. It contributes to a vast number of people who will be affected during the flood event. The development of Kelantan is not as fast as the state in the Klang Valley area. Therefore, the numbers of utilities are not as many as others. Most utility points are far from people except for petrol stations. Due to that reason, there are no significant changes made to the impact threshold. The numbers are based on the literature review and workshop discussion.

4.2 Flood Risk Matrix for Sungai Kelantan

The Flood Risk Matrix (FRM) in Sungai Kelantan was developed by determining the scoring value by integrating receptors' impact with 16 flood scenarios and the flood depth as weightage. Figure 4 shows the Flood Risk Matrix (FRM) of Sungai Kelantan at the worst flood event; 1100 mm rainfall depth. Figure 4 shows that the severe impact will occur mainly in the downstream area involved Kota Bharu district at 1100 mm rainfall depth. This reflects that all receptors' total scoring was more than 9, with flood depths from Flood Hazard Map being more than 2 m. It can also be observed that there were also severe impacts in Machang, Kuala Krai and Jeli district area. Figure 5 shows the grid's details that produce 18 in its final score; the highest score for Flood Risk Matrix (FRM). This grid is located at Tumpat, Kelantan.

As we can see in Fig. 5, the height field indicates the flood depth shows 1.999 m. This may reflect the flood depth is either 2 m or more. We can also observe that the agricultural area's percentage impacted in the 1 km^2 grid is 87.7% and results in a high impact score, 3. The number of housing in this 1 km^2 grid is 304 units of the house per grid with 3. This is followed by the population where it estimates 1520 people per grid, giving an impact score for the population as 3. The number of public facilities in this grid is 38 and marks this receptor's impact level as 3. The road and railway length in this grid is 6.948 kms and gives an impact level score of 3. There was 2 transportation infrastructure in this grid that involved Taxi Terminal and Station. This gives the transportation infrastructure impact level is equal to 2, which classified as a significant impact. The final receptor is the utility receptor that marks 3 number of utilities involving transmission towers in the grid. This contributes to scoring 1, the minor impact on utility receptors. The total score sums up all receptors and final score scores integrate the height of flood depth by weightage. The final score is equal to 18, where it was categorized as *severe* impact.

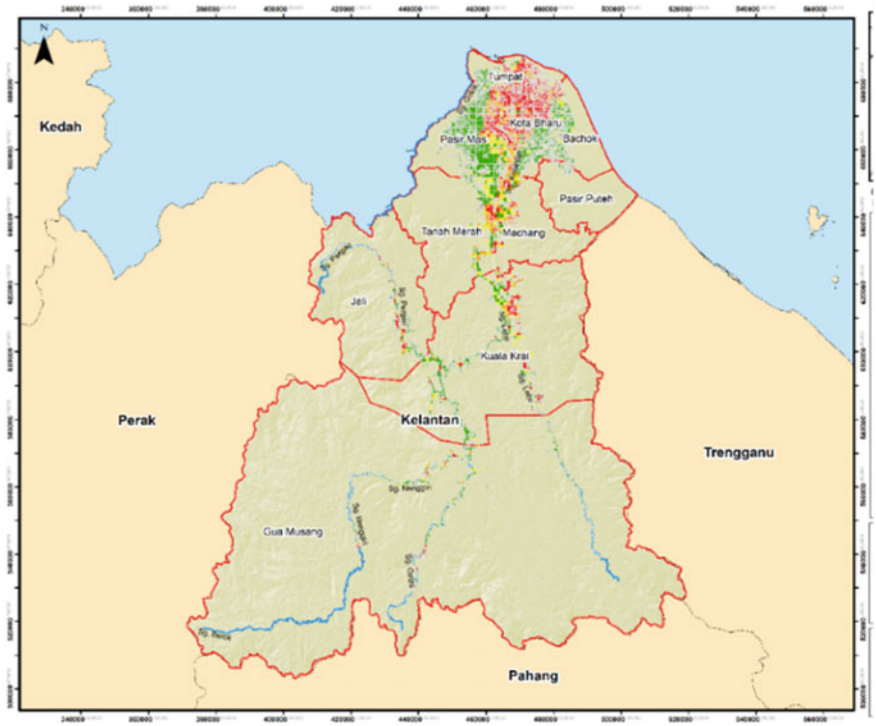


Fig. 4 Flood risk matrix (FRM) for 1100 mm rainfall depth

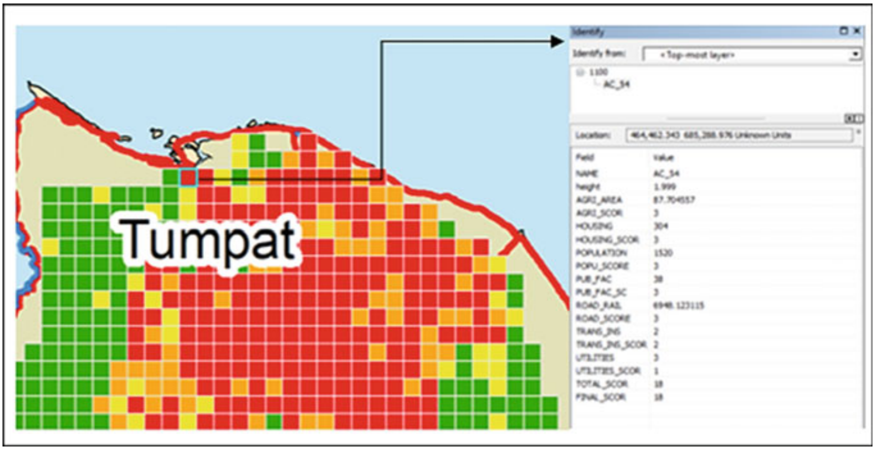


Fig. 5 Highest FRM score grid identity

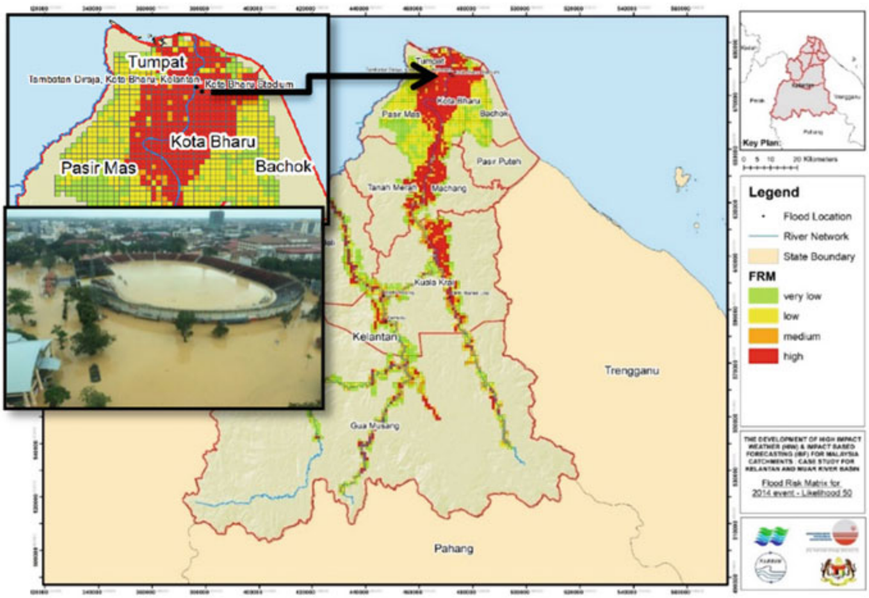


Fig. 6 Flood risk matrix based on 2014 event

4.3 Verification Flood Risk Matrix for Flood 2014

The flood management system's efficiency is essentially important because it influences two vital components: losses of human lives and property damage. It happens in Kelantan in the year 2004 was mainly due to the continuous heavy rainfall from 21 to 23 December 2014, whereby the water level in the river exceeded those recorded floods in Kelantan until 2014. Figure 6 shows the Flood Risk Matrix based on the revised version of the threshold impact. Kota Bahru stadium has been identified as the severe flood was filled with floodwaters.

This verification indicates that Kota Bahru stadium's particular location is in a red 1 km grid cell that shows high and severe impact based on the revised threshold. This event shows that the areas with an active and high concentration of development activities and densely populated regions with significant infrastructure investment are more vulnerable than other areas. Likewise, some areas are not highly prioritized for flood protection. This is because there is nothing valuable to protect or are not the most critical to flooding. Therefore, the most vulnerable areas in the Kelantan River basin are identified and flood risk matrix indices of each place in a 1 km grid cell were generated concerning flooding areas and threshold impact. It can be concluded that the threshold number has made a significant impact on to flood event 2014 and it can be considered an excellent parameter to predict the area.

5 Conclusion

The complete result of FRM shows that the impact of floods can be predicted early in the Kelantan area. The FRM is the summation of all receptors such as public facilities, agriculture, population, housing and properties, road network, infrastructure transportation and utilities. In this research, the analysis of FRM was made with the highest number of flood hazard maps, i.e. 1100 mm. Based on the result obtained with a comparison on the 2014 flood event, the results validate that the FRM produced is accurate and reflects the threshold and flood location. The impact threshold in Kelantan has been verified and agreed upon by government agencies with local expert authority. In the future, the range of impact thresholds can be tested with other states. This is to ensure that the threshold can be used in the whole of Malaysia.

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Dams and Slope Mitigation

Hydrodynamic Simulation and Dam-Break Analysis Using HEC-RAS 5

Darshan J. Mehta, Sanjaykumar M. Yadav, Nikunj K. Mangukiya, and Zalak Lukhi

Abstract The Ukai Dam is built on the Tapi River in Gujarat, mainly for agricultural activities, power generation, and flood control. However, large potential energy from the Ukai Reservoir would impose a risk of sudden breach of containment leading to loss of life and property at Surat city in the downstream area. This paper is deemed to provide a dam-break analysis of the Ukai Dam to generate a breach hydrograph and flood map as a result of the dam-break event under piping and overtopping failure. The process of collecting and preparing data, estimating breach parameters, developing a one-dimensional and two-dimensional unsteady flow model in HEC-RAS 5 software, performing dam-break analysis, and mapping of flood propagation are outlined in this paper. The result shows that the peak discharge of the dam-breaking flood hydrograph is 237759 $m^3\ s^{-1}$ with a maximum velocity of 9.18 $m\ s^{-1}$, and a maximum water surface elevation is 35.68 m. The computed hydraulic parameters through simulation can be useful for preparing flood hazard risk maps and emergency action plans.

Keywords Dam-break · Flood · HEC-RAS 5 · Hydrodynamic model

1 Introduction

The dam brings many benefits to society, but some of the most destructive events of the last two centuries have also been triggered by floods arising from the failure of constructed dams [1]. Dam-break event is of special interest, though it occurs rarely its occurrence can be very devastating, causing more casualties and damages than any other man-made structure failure [2]. This is because of the flood wave's intrinsic disruptive force that will be unleashed as a consequence of a sudden failure [1]. The dam can be vulnerable to failure due to various reasons, depending on the

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type of dam and site-specific locations. Some of the reasons include overtopping, piping or seepage, structural overstressing of dam components, surface erosion due to high velocity and wave action, internal erosion, earthquake, and seismic failure [3]. Dam breach can be summarized as a partial or catastrophic dam failure leading to an unregulated release of water. Such an event could have a significant impact on the population and the property downstream of the failed structure [4]. If warning and evacuation are not possible, the destructive force of dam-break water waves can be devastating and cause an inevitable loss of life [5]. The transport of significant amounts of sediment or debris as well as the potential for spreading contaminants from sources such as chemical or mine operations in flood-risk areas are additional characteristics of such extreme floods.

The construction of dikes and dams gives people the impression that the floods are fully controlled and that therefore urban and industrial growth takes place in floodplain areas. If these structures fail, then, the damages caused by the flooding would be much higher than it would have been without existence of the structure [6]. Considering the historical failures of the structures, one might ask what can be done to reduce the risk posed by a dam or dike failure event. Analyses of dam-break inundation are used to quantify the possible risks associated with failure of dam, including estimation of the parameter of dam breach, estimation of the hydrograph of dam-break outflow, routing of the dam-break hydrograph, and estimation of the flood inundation extent and severity in downstream area [7]. Several dam-break simulation models are used to forecast the geometry and duration of the dam-break [1, 2, 4, 8–11]. In general, dam-break simulation models are based on empirical data obtained from several case studies of the earth and rockfill dam failures. The empirical equations available relate the parameters of dam-break to the properties of the dam and reservoir, such as the shape of reservoir, the volume impounded, size of dam structure, and its erodibility [7]. The one-dimensional (1D) and two-dimensional (2D) hydrodynamic models are used for routing the dam-break outflow hydrograph. In general, 2D hydrodynamic models are used where higher levels of precision are needed or where the flow situations are non-channelized. From these simulated results, flood maps are prepared using geographic information systems (GIS) and on the basis of that high potential impact areas can be identified for the preparation of mitigation measures [10].

In the present study, a dam-break analysis of the Ukai Dam has been carried out to develop dam-break outflow hydrograph and inundation map as a result of the dame-break event under overtopping and piping failure. The required data were collected from dam authorities, municipal corporations, state agencies, and national agencies. These data were used to develop the 1D and 2D unsteady flow model using HEC-RAS v5 software. The calibrated and validated model was used to estimate peak flood discharge, maximum wave velocity, and depth of flood inundation at various locations in the downstream area. The computed hydraulic parameters through simulation can be useful for preparing flood hazard risk maps and emergency action plans.

2 Study Area and Data Collection

The Tapi River is the second-largest west-flowing river in India, which initiates in Madhya Pradesh from the Multai forest in Betul district. The elevation at the beginning is approximately 752 m to the mean sea level. The total length of the Tapi River from the source to the ocean's meeting point is 724 km. It flows 282 km through Madhya Pradesh, 228 km through Maharashtra, and 214 km through Gujarat to merge into the Arabian Sea at Dumas, approximately 19.2 km west of Surat city. As shown in Fig. 1, the Tapi River basin is divided into three sub-basins, among which lower Tapi basin was considered as the study area. The estimated length of lower Tapi River is 122 km. The Ukai Dam is a large reservoir located at the beginning of lower Tapi River, supplying almost half of its drainage to hydropower generation, agriculture, and other facilities. The Ukai Dam is located approximately 29 km upstream of Kakrapar Weir. The catchment area up to the dam site is 62,225 km^2. The live storage capacity of the Ukai Reservoir is 7369 MCM with a water spread of approximately 600 km^2 at its Full Reservoir Level (FRL) of 105.156 m. The maximum water level (MWL) of 106.99 m is expected to be attained by the reservoir when passing the probable maximum flood (PMF) of 59,920 m^3 s^{-1}. Figure 2 shows the picture of the Ukai Dam. The Ukai Dam is a combination of concrete and embankment dam with a maximum height of 80.77 m from its lowest foundation. The overall length of the dam is 4927 m, of which the zoned fill type of earth dam is 4058 m and the remaining length is occupied by a masonry gravity dam. The 425.2 m long spillway is provided with a total of 22 radial crest gates of size 15.55 m × 14.78 m. The maximum discharge capacity of spillway is 46,270 m^3 s^{-1} at MWL and 37,860 m^3 s^{-1} at FRL. The water released from the powerhouse of the Ukai Dam is stored in the Kakrapar

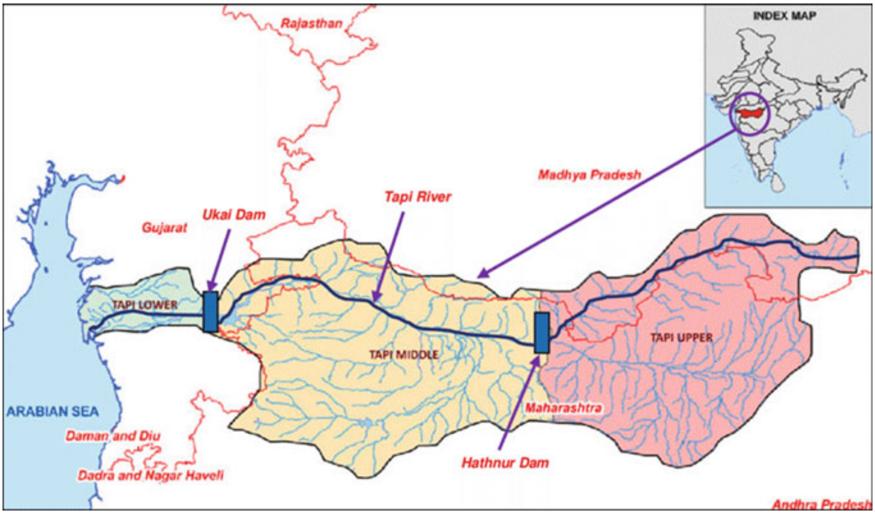

Fig. 1 Sub-division of Tapi basin. *Source* iomenvis.nic.in

Fig. 2 Picture of Ukai dam. *Source* guj-nwrws.gujarat.gov.in

Weir in order to improve irrigation of the Kakrapar scheme. The Kakrapar Weir and Singanpor Weir are the two inline structures on lower Tapi River. Total four river gauging stations are located on lower Tapi River, which are Hope Bridge, Singanpor Weir, Ghala, and Kakrapar Weir.

The details about 313 river cross-sections for one-dimensional modeling are collected from the Surat Municipal Corporation (SMC) and the Surat Irrigation Circle (SIC). The hourly and daily discharge data of the Tapi River at the Ukai Dam, elevation-storage data, the cross-section of the dam, and gate opening data of the dam are collected from the Ukai Dam Authorities. The cross-sectional details of Kakrapar Weir and Singanpor Weir are collected from SIC and SMC respectively. The tidal level data of the Arabian Sea at Dumas are collected from Gujarat Maritime Board (GMB), Surat. The stage hydrograph of intermediate gauging stations is collected from State Water Data Centre (SWDC) and Central Water Commission (CWC), Surat. For the bathymetry data of two-dimensional hydrodynamic modeling, Shuttle Radar Topography Mission (SRTM) Digital Elevation Model (DEM) of 30 m grid interval are downloaded from the United States Geological Survey (USGS) Earth explorer portal.

3 Methodology

The methodology includes data collection, development of the one-dimensional and two-dimensional hydrodynamic model, estimation of dam-break parameters, and dam-break analysis. Figure 3 shows the flowchart of methodology.

The one-dimensional hydrodynamic model for 122 km of river length has been developed using the U.S. Army Corps of Engineers Hydrologic Engineering Center's River Analysis System (HEC-RAS v5) software. The geometry data of the Tapi River and the Ukai Dam are generated from SRTM DEM using ArcGIS v10.5 and given as input to HEC-RAS. The cross-sectional data and structural data collected from SMC, SIC, and the Ukai Dam Authorities have been entered in geometry files. The water level of the reservoir was given as the initial condition, and the flow hydrograph and gate openings of inline structures were given as boundary conditions for the simulation. The one-dimensional hydrodynamic model has been calibrated for the Tapi River flood event of 2006. The range of the channel roughness coefficient for calibration was taken from the literature [12] based on the original geographic condition of the channel bed. For the performance assessment of the model, Root Mean Square Error (RMSE) has been calculated. The calibrated model

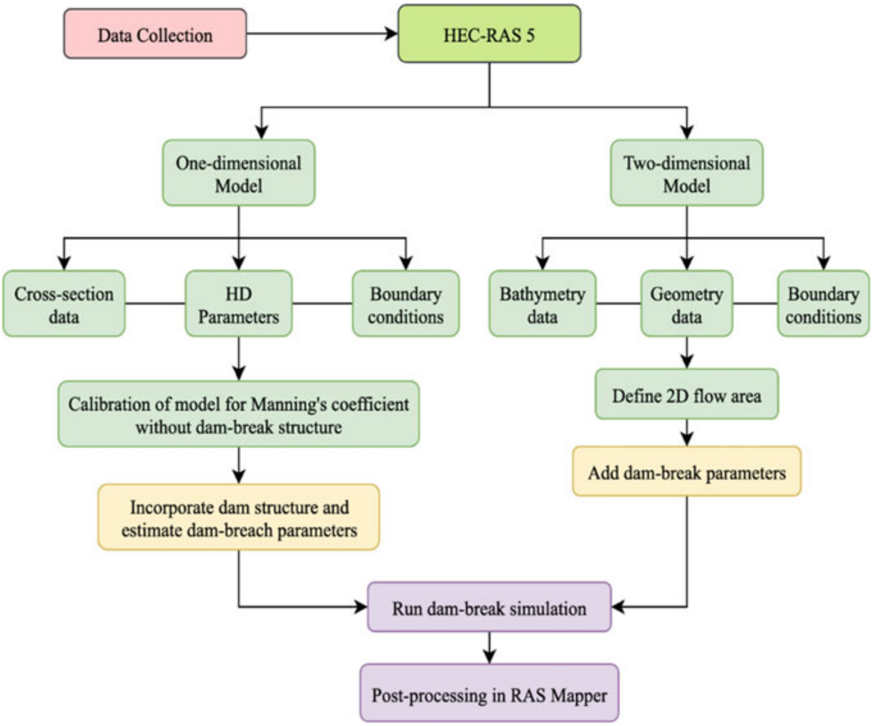

Fig. 3 Flowchart of methodology

is then validated by comparing simulated and observed levels of water at intermediate gauging stations.

The two-dimensional hydrodynamic model for dam-break simulation has been developed using HEC-RAS and RAS Mapper. The pre-processed DEM was given as input to RAS Mapper for the preparation of the bathymetry. The elevation-storage data of the Ukai Reservoir was given as an upstream boundary condition. The embankment station-elevation and spillway gate data of the Ukai Dam, Kakrapar Weir, and Singanpor Weir were also incorporated into the model as boundary conditions. For simulation, a computational mesh with a 100 m spacing in X and Y directions was generated. The dam-breach parameters for the Ukai Dam were calculated using the regression analysis method as specified by Froehlich (1995) [13]. Froehlich's regression equation for breach width and failure is given in Eqs. 1 and 2. Post-processing of the simulated model was performed using RAS Mapper to generate a flood map, breach hydrograph, and hydraulic parameters.

$$B_{\text{avg}} = 0.1803 K_0 V_w^{0.32} h_b^{0.19} \tag{1}$$

$$t_f = 0.00254 V_w^{0.53} h_b^{-0.9} \tag{2}$$

where, B_{avg} is average breach width (m), K_0 is constant (1.4 for overtopping failure), V_w is reservoir volume at the time of failure (m^3), h_b is the height of the final breach (m), and t_f is breach formation time (h).

4 Results and Discussion

The one-dimensional hydrodynamic model has been calibrated and validated for the Tapi River flood event of 2006. The range of Manning's coefficient of roughness for calibration was taken from 0.022 to 0.035 according to the literature [12]. RMSE (m) has been calculated for the comparison of the simulated and observed water levels. The simulated model shows a minimum RMSE at different gauge stations with Manning's coefficient of 0.03 as shown in Table 1. The comparison of the simulated and observed water levels is shown in Fig. 4.

Table 1 Comparison of simulated and observed stage hydrographs for different Manning's roughness coefficient

Manning's 'n'	Mandvi bridge	Ghala	Nehru bridge	Weighted RMSE
0.022	1.735	1.453	2.179	1.747
0.025	1.565	0.877	2.007	1.645
0.030	1.166	0.987	1.256	1.163
0.035	1.239	1.002	1.845	1.537

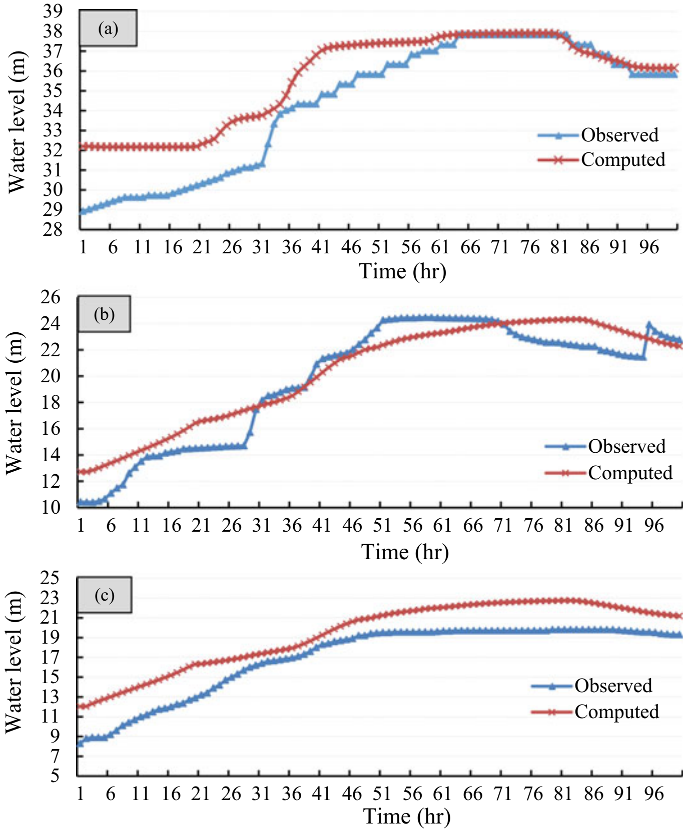

Fig. 4 Comparison of observed and simulated stage hydrograph corresponding to Manning's coefficient as 0.03 **a** at Mandvi bridge, **b** at Ghala, and **c** at Nehru bridge

The two-dimensional dam-break simulation has been performed incorporating the elevation-storage data of the Ukai Dam and Kakrapar Weir and Singanpor Weir inline structure as shown in Fig. 5. The dam-breach parameters for the Ukai Dam have been calculated using the Froehlich (1995) regression analysis method and shown in Table 2. The simulated results were mapped using RAS Mapper. The Tapi River flood event of 2006 is simulated for 16 h, i.e., 07/08/2006 09:00 h. to 08/08/2006 00:00 h. The result shows that the peak discharge of the dam-breaking flood hydrograph is 237,759 $m^3 s^{-1}$ with a maximum velocity of 9.18 $m s^{-1}$ as shown in Fig. 6, and a maximum water surface elevation is 35.68 m. The inundation depth and velocity results for the entire area are shown in Fig. 7. The villages which are most affected by the dam-break flood are Baleshwar, Beddha, Bhatkhai, Bhurivel, Bori, Ghantoli, Jamapur, Khoj, Kikvad, Limbi, Pipalvada, Sedhav, Serulla, Silatvel, Surat, Umarsadi, Vada, Vadhva, Vaghecha, Vaghnera, and Valargadh. Surat city is located downstream; it is divided into seven different zones. The simulated results show that the water

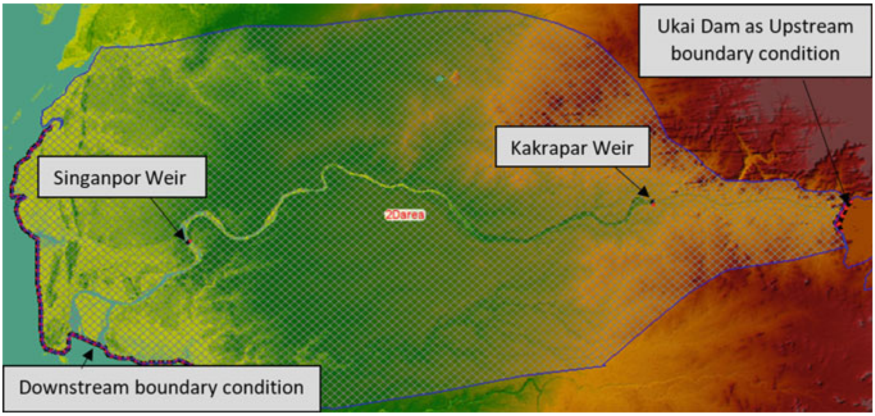

Fig. 5 2D mesh area and inline structure

Table 2 Estimated dam-breach parameters based on Froehlich (1995) for 2D

Breach parameter	Formulae	Calculated value for Ukai dam
Average width (m)	$B_{avg} = 0.1803K_0V_w^{0.32}h_b^{0.19}$	778
Side slope	1.4 for overtopping	1.4H:1 V
Formation time (h)	$t_f = 0.00254V_w^{0.53}h_b^{-0.9}$	10.88

takes between 5 and 6 h to reach Surat city. The highest flood depth in the Surat city is 13.34 m in the West zone followed by 12.29 m in the North zone, 11.58 m in the South-East zone, 11.4 m in the South zone, 10.56 m in the East zone, 10.21 m in the South-West zone, and 8.32 m in the Central zone.

5 Summary and Conclusions

Dam-break event is a comprehensive and complicated process, and the mechanics of actual failure are still not well understood. In this paper, the attempt has been made to simulate a dam-break flood using the Froehlich (1995) regression equation for overtopping failure as suggested in the HEC-RAS software manual and training documents. The one-dimensional and two-dimensional hydrodynamic model for dam-break simulation has been developed for the inflow of the 2006 flood in the Ukai Dam.

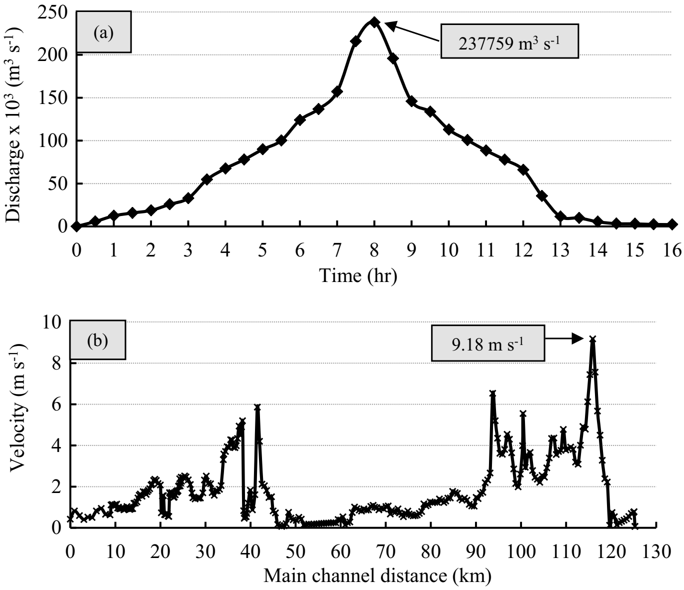

Fig. 6 **a** Dam-break flood hydrograph for the Ukai Dam, and **b** the profile velocity plot for dam-break flood simulation

The results of the one-dimensional hydrodynamic model show that Manning's roughness coefficient of 0.03 gives a minimum RMSE between observed and simulated water levels for the lower Tapi River. The results of the two-dimensional hydrodynamic model show that the peak discharge of the dam-break flood hydrograph would be 237,759 $m^3\ s^{-1}$, which is seven times higher than that of the 2006 flood in the Ukai Dam. The peak velocity of the dam-break flood hydrograph is 9.18 $m\ s^{-1}$. The maximum inundation depth is 35.68 m near Surat city. The flood inundation map shows that many villages including Surat city would be flooded by dam-breaking floods. The highest flood depth in the Surat city is 13.34 m in the West zone followed by 12.29 m in the North zone, 11.58 m in the South-East zone, 11.4 m in the South zone, 10.56 m in the East zone, 10.21 m in the South-West zone, and 8.32 m in the Central zone.

The hydraulic parameters computed through simulation will help to design flood protection measures and development of flood inundation maps for the downstream area of the dam. A proper analysis of the risks associated with dam failures can help to prepare land use and establish emergency plans in order to minimize the catastrophic loss to human life and property.

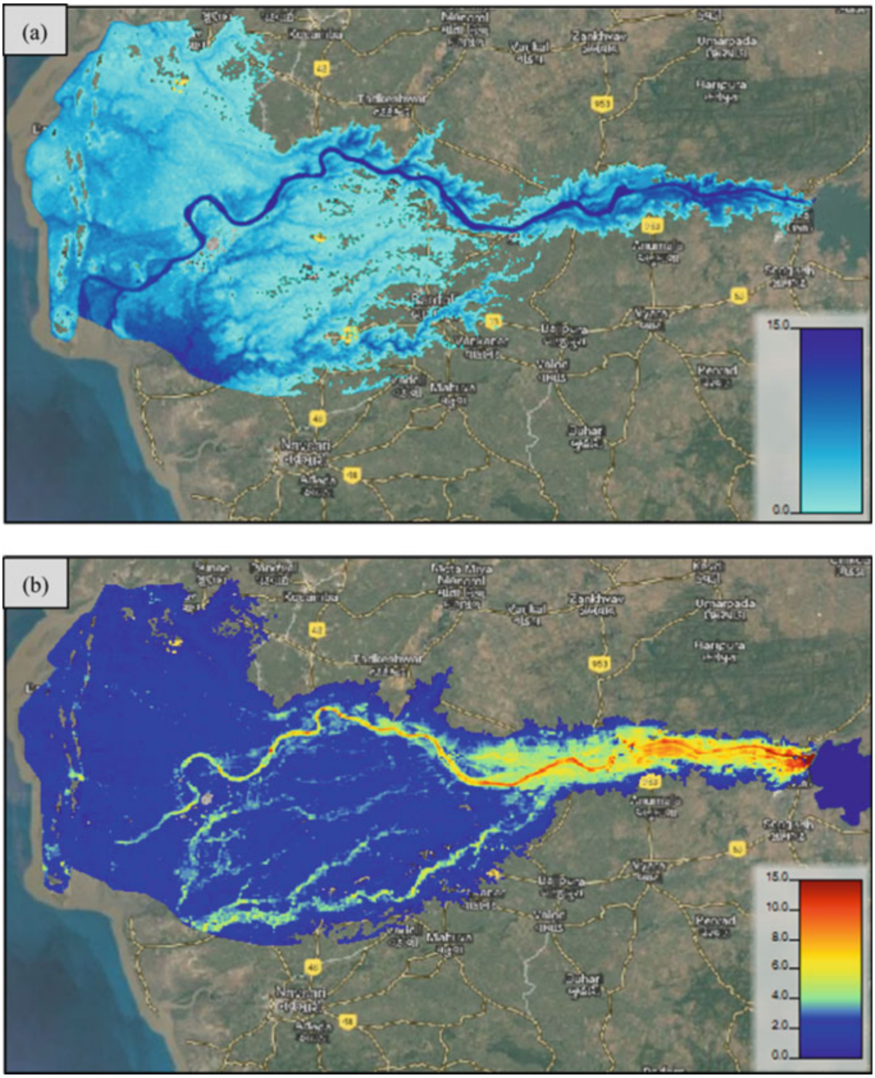

Fig. 7 **a** Inundation depth map, and **b** velocity magnitude plot

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Dam Safety—Living with the Risk of Failure

David C. Froehlich and David Gonzalez Diaz

Abstract Dams provide numerous benefits, including flood protection, water supply, hydropower, irrigation and recreation. However, a dam also creates a potential hazard to people and property should a failure occur, leading to an uncontrolled release of impounded water. The effect of such an incident needs to be calculated to establish the risk of failure, particularly to the downstream inhabitants who would be affected. Key elements of this evaluation are maps that outline the area inundated by a dam-failure flood at a scale sufficient to identify the population at risk along with the critical infrastructure that would likely be damaged. Numerical models are used to assess the consequences of a potential failure and produce the essential flood inundation maps. The models are based on the solution of either one-dimensional cross-section-averaged (1D) or two-dimensional depth-averaged (2DH) unsteady open-channel flow equations. This analysis presents the results of both 1D and 2DH simulations of the flood caused by a potential breach of Hirakud Dam, a large dam in east-central India that impounds an enormous volume of water. Comparison of the generated inundation mapping shows mostly close agreement between the 1D and 2DH solutions. Although a 2DH model does have advantages where the 1D flow assumptions become unrealistic.

Keywords Dam safety · Dam breach · Flood · Emergency action plan · Flood risk · Flood mapping · Flood model

1 Introduction

India ranks third in the world after China and the United States in its number of large dams. These structures have been crucial in promoting rapid and sustained agricultural and rural growth and industrial development. However, they also present risks to those living downstream from them if they are not maintained and operated

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correctly. Although dam failures leading to uncontrolled releases of impounded water are infrequent, their impacts are usually catastrophic, with disastrous consequences that far exceed those from typical floods. An ever-increasing number of people live and work in areas that would be vulnerable to sudden flooding from India's dam failures.

Many people who live in areas inundated by an uncontrolled release of water from a dam are entirely unaware of the hazard looming upstream. Dam-failure floods are almost always more sudden and violent than regular river floods. However, even massive, controlled releases from a reservoir can be dangerous if sufficient warnings are not given to the downstream population. Adequate emergency preparedness and effective and sustainable dam safety programs can dramatically reduce the risk of failure.

Managing the contingencies caused by the failure of a dam and the uncontrolled release of water requires the coordinated efforts of both the dam owning/operating agencies and disaster management authorities. The beginning of such an undertaking is an Emergency Action Plan (EAP). An EAP for a dam is a written document that identifies potential emergency conditions and specifies preplanned actions to be followed in case of a potential emergency. A crucial element of an EAP is a mapping that outlines the area inundated by a dam-failure flood at a sufficient scale to identify the population at risk and dwellings, roads, low-water crossings and other critical structures likely to be directly affected. The travel time for floods to reach specific locations is one of the vital parameters to be evaluated. Others are the depth of flooding and velocity of flows, which indicate the flood severity.

Numerical models are used to assess the consequences of a potential failure and produce flood inundation maps. The models are based on the solution of either one-dimensional cross-section-averaged (1D) or two-dimensional depth-averaged (2DH) equations that describe the unsteady open-channel flow. In this analysis, the flood resulting from a breach of Hirakud Dam is simulated using both 1D and 2DH numerical models and the results are compared.

Both the 1D and 2DH models are shown to provide nearly the same estimates of the maximum water depth, the arrival time of the flood peak and the maximum water speeds at 32 index points located throughout the floodplain. However, the initial flood-wave arrival times differ slightly along the main river channel. Several advantages of the 2DH simulations are described.

2 Hirakud Dam

Hirakud Dam (Fig. 1) is a composite structure of earth, concrete and masonry. It spans the Mahanadi River, about 13 km upstream from Sambalpur in Odisha, India. It is the longest dam in India, measuring 25.8 km from end-to-end, including dikes, which fill low points between the adjacent hills. The main dam has an overall length of 4.8 km. The reservoir created by the dam is enormous, impounding nearly 6000 Mm^3 at the full-supply level (FSL).

Fig. 1 Hirakud Dam in Odisha, India

The vast floodplain immediately downstream from the dam (Fig. 2) is dotted with small hills and confluences with several tributary streams that drain urban districts. One of the urban areas is Sambalpur, the fifth largest city in Odisha. It is located on the banks of river Mahanadi, with a population of 335,761 (as per the 2011 census). Since the completion of Hirakud Dam in 1956, Sambalpur has undergone a significant transformation, supporting many agriculture-related businesses and metal-processing industries. Several educational institutes are about 5 km downstream from the dam at Burla, known as the education hub of Odisha.

3 Dam-Breach Model

In this analysis, breach development is considered to proceed in a presupposed way, growing in a trapezoid shape defined by its final dimensions and the time needed for the breach to form completely. Froehlich's [1] formulas were used to predict the parameters of a hypothetical failure of Hirakud Dam caused by overtopping. The average width of the final breach is calculated as follows:

$$B_{avg} = 0.28 \times k_M \times k_H \times \frac{V_w^{1/3}}{H_b} \times \left(\frac{W_{avg}}{H_b}\right)^{-1/6} \times H_b \tag{1}$$

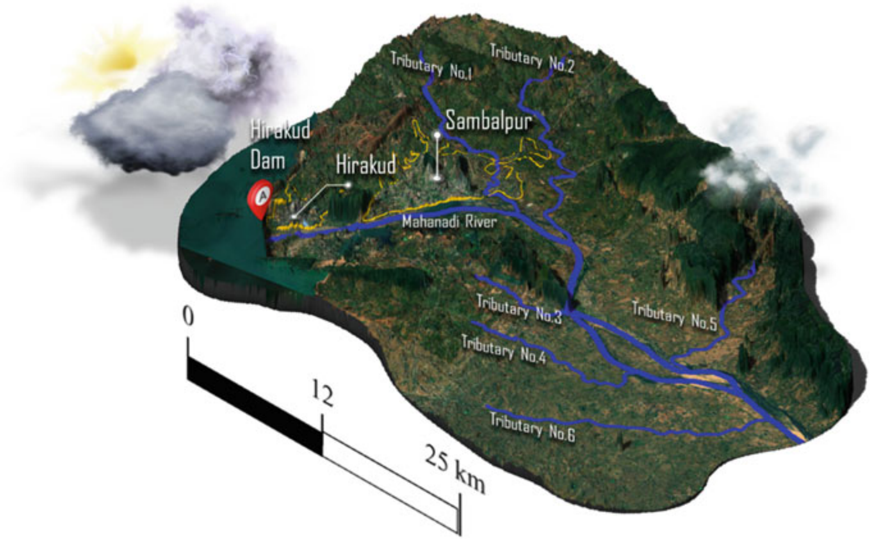

Fig. 2 Hirakud Dam and the downstream floodplain showing the Mahanadi River and the several tributaries that drain urban districts

where, V_w = the impounded volume of water above the final breach bottom elevation, W_{avg} = the average width of the embankment (from the upstream toe to the downstream toe) above the final breach bottom, H_b = the height of the final trapezoidal breach,

$$k_M = \begin{cases} 1.0, & \text{for internal erostion} \\ 1.5, & \text{for overtopping} \end{cases}, k_H = \begin{cases} \left(\frac{H_b}{H_s}\right)^{1/2}, & \text{for } H_b < H_s \\ 1.0, & \text{for } H_b \geq H_s \end{cases},$$

and $H_s = 6.1$ m (or 20 ft if U.S. Customary units are used). The average breach side-slope ratio m is given as

$$m = \begin{cases} 0.6, & \text{for internal erosion failures} \\ 1.0, & \text{for overtopping failures} \end{cases} \tag{2}$$

The breach formation time (in seconds) is found as

$$t_f = 50 \times \sqrt{\frac{V_w}{g H_b^2}} \times \left(\frac{W_{avg}}{H_b}\right)^{1/4}. \tag{3}$$

where g = gravitational acceleration.

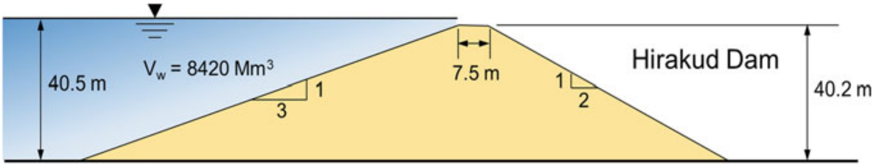

Fig. 3 Cross-section of Hirakud Dam earthen embankment where breaching occurs

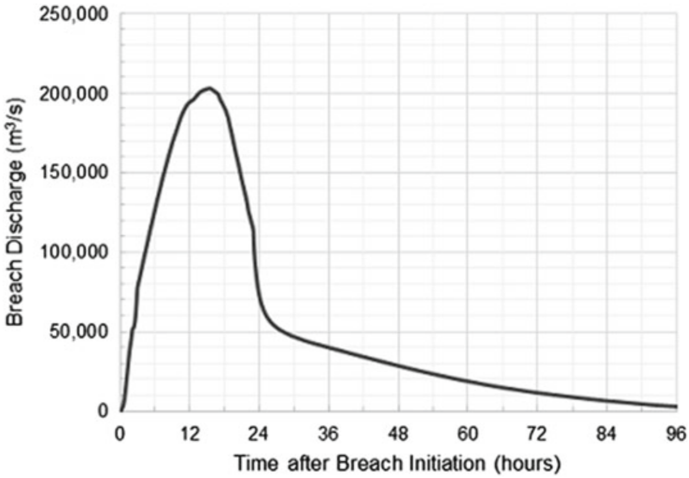

Fig. 4 Dam breach flood hydrograph

A cross-section of the earthen embankment section of Hirakud Dam where a breach is likely to form is shown in Fig. 3. For an overtopping failure of Hirakud Dam V_w = 8,420 Mm^3, H_b = 40.2 m and W_{avg} = 108 m. Then with k_M = 1.5 and k_H = 1.0, Eqs. (1), (2) and (3) give: B_{avg} = 725 m, m = 1.0 and t_f = 46,650 s = 12.96 h (rounded to 13.0 h). The dam-breach outflow flood hydrograph, which is input to both the 1D and 2DH models, is shown in Fig. 4.

4 Numerical Flood Models

The HEC-RAS (Hydrologic Engineering Center—River Analysis System) 1D and 2DH surface-water flow models [2] were used to simulate Hirakud Dam-failure floods caused by the breach in the main section of the earthen embankment. The 1D model is particularly applicable to long, well-defined river reaches. However, flood inundation studies that involve relatively flat terrain often have divided flows or require precise differentiation of flooding depths and durations (such as in high population areas) may require a 2DH model or a combined 1D-2DH model. Both

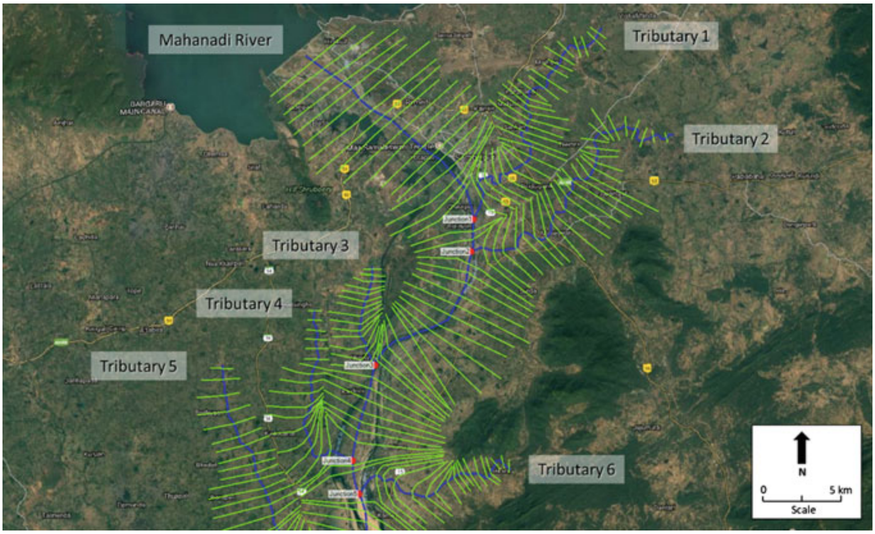

Fig. 5 The layout of the 1D model cross-sections along the Mahanadi River and six tributary streams. Tributaries 1 and 2 flow through the urban center of Sambalpur

the 1D and 2DH models solve the unsteady conservation equations for momentum and mass. However, different solution schemes are used. Details are given by Bruner [2].

The cross-section locations used to model the Mahanadi River and the six tributaries in the floodplain downstream from the dam are shown in Fig. 5. The two-dimensional computational mesh used to model depth-averaged flows downstream of the dam is shown in Fig. 6. Note that Sambalpur is covered by smaller cells than are used to model the remainder of the floodplain where 200 m × 200 m cells were used to construct the mesh. The refined mesh is needed to discretize adequately the two tributaries that flow through the urban district.

5 Comparison of 1D and 2DH Flood Simulation Results

Flood simulation results are compared at 32 index points, which are described in Table 1. The index points are located along the Mahanadi River and throughout the floodplain, as shown in Fig. 7. The comparison locations are ordered and numbered by their straight-line distances from the breach. The index point closest to the breach is Hirakud Bus Stand (No. 1) and the farthest point from the dam is Tababda (No. 32), which is located 39 km downstream from the dam measured along the Mahanadi. The flood-wave arrival times (the initial arrival time and the peak arrival time at which the maximum water depth was reached) at the index points are compared in

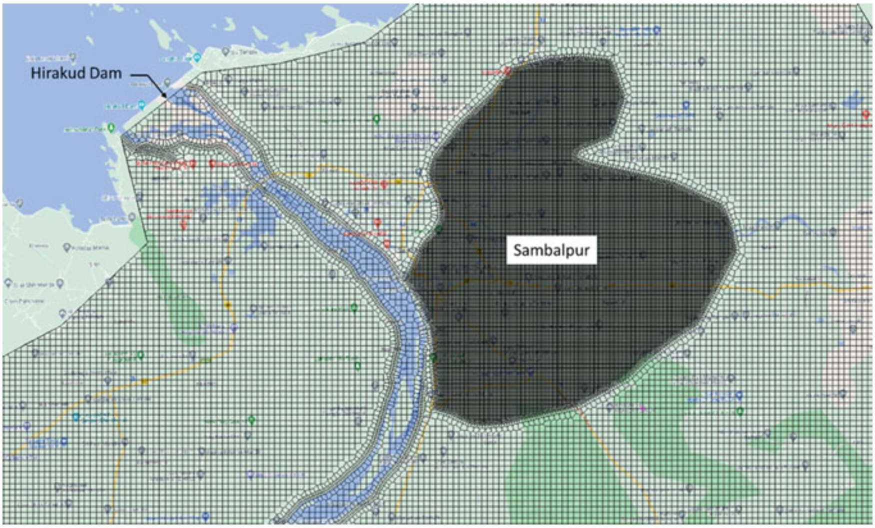

Fig. 6 Two-dimensional mesh of the Mahanadi River floodplain below Hirakud Dam. The urban center of Sambalpur is covered by smaller cells than in the surrounding floodplain

the bar graphs shown in Fig. 8. The maximum water depths are shown in Fig. 9. The maximum computed water speeds are compared in Fig. 10.

At five of the index points (Nos. 4, 6, 13, 15 and 18), located near the edge of the inundated floodplain, the 1D solution finds that the points are not flooded. This disagreement is caused by the interpolation between cross-sections that is needed to calculate values. Only at Nos. 4 and 5 (located close to the dam) were 2DH maximum water depths significant. The maximum water depths compared in Fig. 9 are remarkably close at all index points except those near the dam (Nos. 1 through 4). Similarly, the maximum water speeds are close at most index points except those near the dam (Nos. 1 through 5).

From Fig. 8, the most significant differences between the 1D and 2DH flood model results are the arrival times of the initial flood wave. The 1D flood-wave initial arrival time is shorter at most index points because flows at first are all confined to the main channel. In contrast, the 2DH solution allows water to spread across the floodplain immediately upon release through the breach. However, the peak flood-wave arrival times are nearly the same at all locations, resulting from the lengthy breach time (13 h) and flooding duration.

Table 1 Flood index point descriptions

No	Index Point Name	Distance[a] from the dam (km)	Location	
			Latitude	Longitude
1	Hirakud Bus Stand	2.538	21.52756	83.89874
2	Burla N.A.C. College	3.424	21.50590	83.88856
3	Burla	5.138	21.48864	83.88447
4	Sri Ram Vihar	6.882	21.47510	83.89570
5	Remed	8.204	21.49988	83.94542
6	Sikirdi	9.212	21.46687	83.92742
7	Nirankari Colony	9.440	21.48492	83.94958
8	Khetrapur	9.9460	21.48764	83.95732
9	Potapali	10.566	21.46735	83.94796
10	Modipada	11.817	21.47557	83.97051
11	Mundoghat	12.205	21.45892	83.96123
12	Sangsinghari	12.437	21.43396	83.92925
13	Budhajar	12.555	21.48042	83.98188
14	Barhakuni	12.868	21.45151	83.96243
15	Sambalpur	13.275	21.46683	83.98117
16	Jampali	14.489	21.43365	83.96462
17	Chaupur	14.587	21.43812	83.97147
18	Gengutipali	14.957	21.46577	83.99963
19	Jharapali	15.427	21.42699	83.97021
20	Gopal Bihar	15.894	21.44228	83.99297
21	Basantput	16.000	21.39497	83.91621
22	Naksapali	16.457	21.45988	84.01271
23	Brahmapura	16.855	21.41181	83.97180
24	Senhapali	18.210	21.39382	83.96658
25	Gunderpur	18.671	21.40668	83.99298
26	Bakbira	20.135	21.36293	83.94017
27	Jayghant	20.257	21.37641	83.97393
28	Chipilima	20.677	21.35016	83.90825
29	Mahanadi	21.839	21.34341	83.92810
30	Kardola	22.731	21.33055	83.90168
31	Marangola	23.362	21.32454	83.89903
32	Tababda	28.546	21.27908	83.91354

[a]The straight-line distance measured from the centre of the dam breach

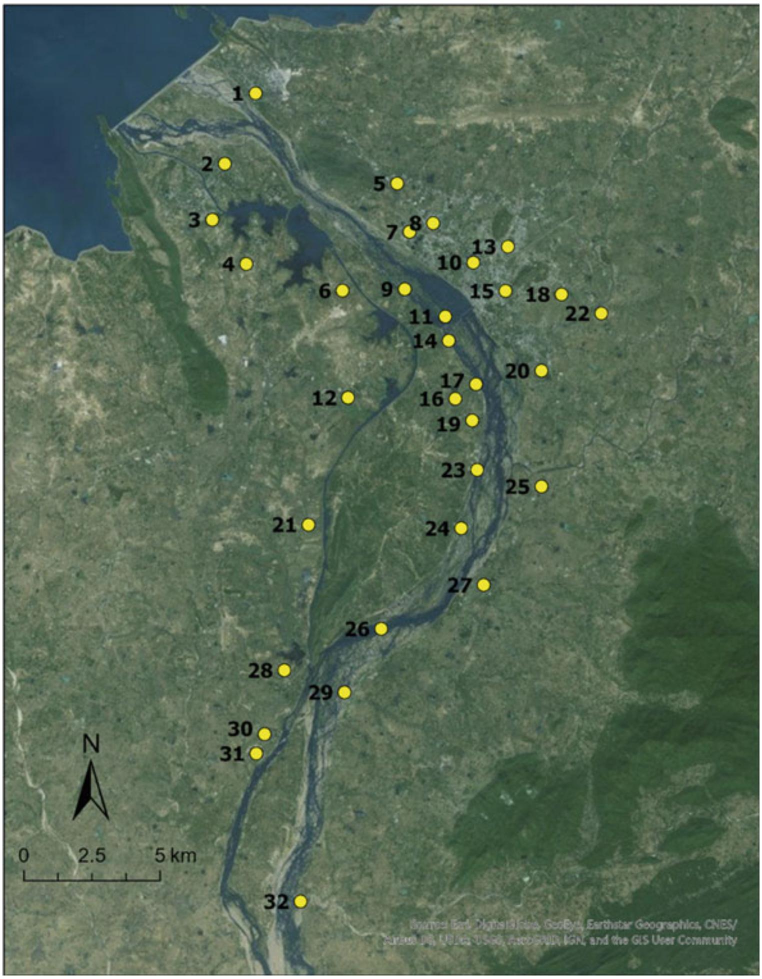

Fig. 7 Locations of the 32 flood index points downstream from Hirakud Dam

6 Summary and Conclusions

Both 1D and 2DH numerical models are used to assess the consequences of a dam breach and produce flood inundation maps. The type of model chosen is determined mainly by the physical characteristics of the river channel and floodplain. The comparison of dam-breach flood simulations by 1D and 2DH models in this study finds close agreement between the maximum water depths and flow speeds, except at several index points closest to the dam where the 2DH governing equations provide more accurate descriptions of the flow. The arrival time of the initial flood wave given by the 1D solution is consistently less than the 2DH calculation. Of course, good

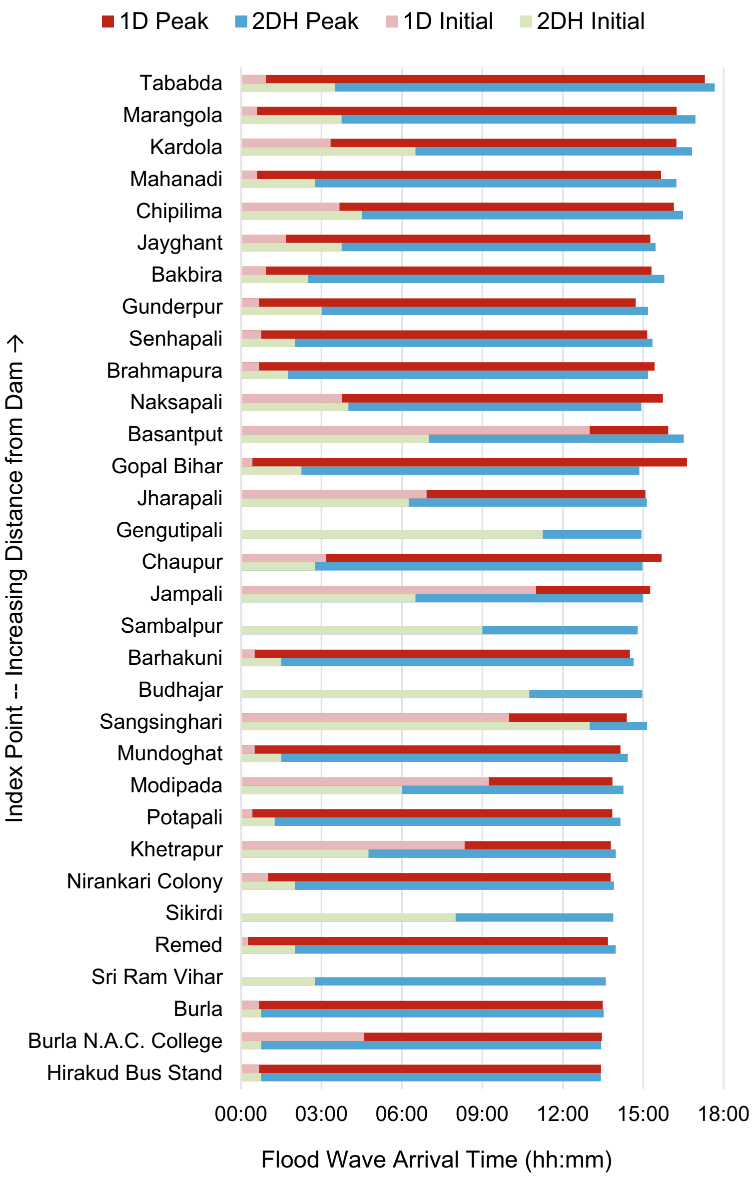

Fig. 8 The initial and peak flood-wave travel times to index points. Distance from the dam increases from the bottom to top

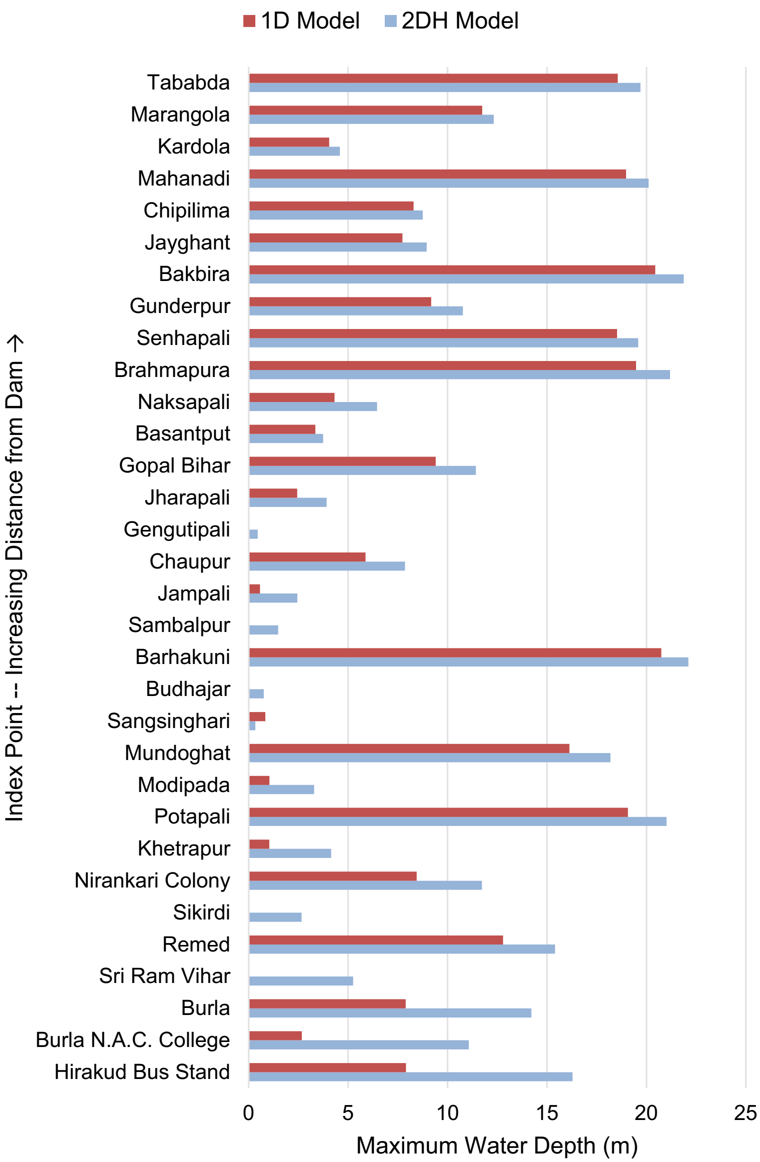

Fig. 9 The maximum water depth at index points from 1 and 2DH model simulations

agreement between the two modelling approaches depends on the skilful layout of cross-sections and construction of two-dimensional meshes.

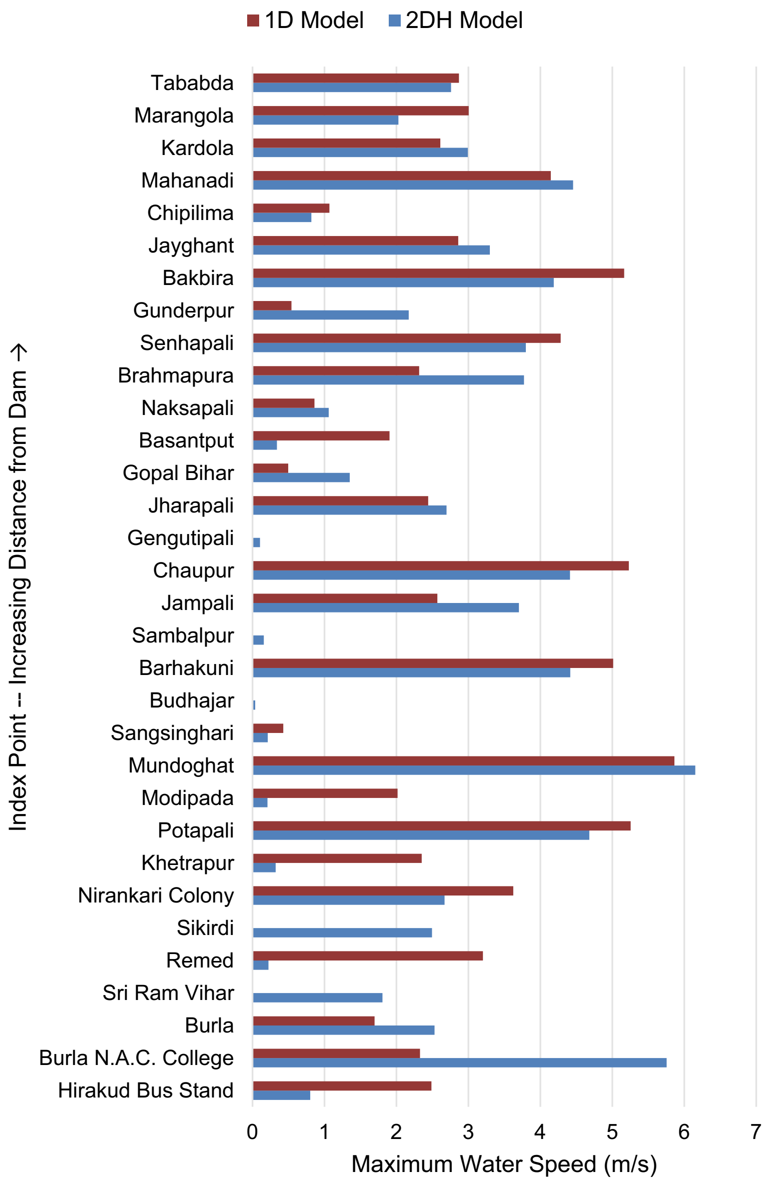

Fig. 10 The maximum water speed at index points from 1 and 2DH model simulations

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Response of Hill-Slope Buildings Subjected to Near-Fault Ground Motion

Prabhat Kumar, Ashwani Kumar, and A. D. Pandey

Abstract The near-fault ground motion (NFGM) is composed of high frequencies, representing accelerations and one or more dominant long-period velocity pulses. This study is intended to analyze and interpret the response of hill-slope buildings under the effect of near-fault pulse-type ground motions in the Himalayan region. For this purpose dynamic analysis of two special moments resistant frame (SMRF) 3D configurations consisting of Step-Back (SB) and Step-Back-Set-Back (SBSB) models have been conducted. From a seismic safety point of view responses due to NFGMs are compared with the responses obtained from conventional types of seismic inputs. The Indian seismic codal spectra need modification to incorporate the effects of pulse-type ground motion due to moderate, large and great earthquakes for sites in the vicinity of fault regions, particularly for the Himalayas region. It has been further recognized that the large amplitude pulses, primarily related to directivity effect, control the response of medium- and long-period structures, whereas, the high-frequency part of the NFGM plays an important role especially for short-period structures.

Keywords NFGM · Long-Period · Velocity pulse · Directivity · Dynamic response · Hill-Slope buildings

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1 Introduction

Dominant source characteristics governing NFGM include: Rupture directivity, Fling-step, Hanging-wall and Vertical effects. Forward rupture directivity is responsible for increased low frequency content of ground motion at distances within 20 km-30 km from the hypocenter [1, 2] and sites close to fault experience large amplitude long-period pulse-motions [3]. NFGM, because of its complex nature, has been represented by equivalent pulse models, such as half-pulse, full-pulse and multiple-pulses models, with pulse-period (T_p). The fundamental controlling parameters of pulse models are: type of pulse, pulse-period and pulse-amplitude [4, 5]. However, it is to be emphasized that the use of equivalent pulse models is an approximation to represent NFGM which is very complex in nature. This aspect has been recognized by a large number of researchers all over the world. The pulse models have helped in quantifying seismic demands for structures in terms of controlling parameters of the NFGM namely, type of pulse, pulse-period (T_p), pulse-amplitude (V_p) and a number of predominant pulses (N) of the models. Near-fault effects have been incorporated in seismic design codes, namely, American UBC-1997, Chinese GB50011-2001 [6, 7] with a view to protecting the structures located in the near-fault regions. However, the Indian standard code of practice IS1893:2016 is silent about NFGM. Hall et al. (1995) examined the effects of NFGM on flexible buildings and emphasized that flexible-frame and base-isolated buildings, designed as per codal provisions, undergo severe non-linear deformations because of large rapid displacement pulses associated with the large long-period velocity pulses [8, 9]. Malhotra (1999) demonstrated that pulse-type ground motion leads to narrower velocity-sensitive regions shifted to longer periods [10]. This leads to an increase in base-shear and inter-story drift in high-rise buildings with an accompanying increase in ductility demand due to high PGV/PGA ratio. Studies have also demonstrated that spectral ordinates obtained from simplified pulse models are strongly related to the velocity spectral period and pulse waveforms [11].

2 Objectives of the Study

The main objective of the present study is to analyze and interpret the response of hill-slope buildings subjected to pulse-type ground motion in the Himalayan region and to compare the response of the buildings on hill-slope subjected to pulse-type ground motion with conventional seismic inputs (Indian seismic codal spectra and site-specific ground motion incorporating the near-fault factor) and make appropriate recommendations.

3 Pulse Characterization of Himalayan Earthquakes Adopting Wavelet Analysis

To allow measuring the SGM due to moderate and large earthquakes in the Himalayas, strong motion arrays were deployed by the Department of Earthquake Engineering, IIT Roorkee. The first strong motion array was installed in the Himachal Himalaya in 1983. SGM due to a moderate 1986 Dharamsala earthquake (Mw = 5.5) was recorded at **nine** stations. SGM of the 1991 Uttarkashi earthquake (Mw = 6.8) was recorded at **thirteen** stations and the 1999 Chamoli earthquake (Mw = 6.5) at **eleven** stations of the strong motion array installed in the Garhwal and Kumaun Himalaya [12]. These **33** strong motion recordings of three moderate sized Himalayan earthquakes have been analyzed for NFGM characterization by Kumar et al. [16].

Pulse characteristics of NFGM for these recordings are extracted adopting pulse detection methodology based on wavelet analysis given by Baker [13, 14]. Several mother wavelets, namely, Daubechies (db4 and db7), Haar (haar), Symlet (sym4), Coiflets (coif2), Reverse biorthogonal (rbio2.4) and Biorspline (bior1.3) have been used to extract the pulse from the velocity time history and predict the value of pulse-period, which is the most important characteristic associated with ground motion. Fault-normal components at three sites are computed using the procedure given by Somerville [15]. Out of the seven wavelets adapted for pulse detection, Daubechies wavelets (db4 and db7) provided the best results based on the pulse-indicators (PI), pulse-periods (Tp), spectral pulse-periods (Tv-p) and spectral shapes. However, the spectra of long-period pulses extracted using Daubechies mother wavelet of order seven (db7) are closer to the long-period spectral amplitudes of the FN components of ground motions at three sites. For the **Uttarkashi and Chamoli earthquakes**, recorded and computed fault-normal components at **Bhatwari and Gopeshwar stations** showed pulse-type ground motion in their velocity time histories. At **Bhatwari station** the pulse-periods of transverse, as well as fault-normal components, are 1.28 s and 1.30 s respectively. At **Gopeshwar station** the pulse periods of transverse and fault-normal components are 1.37 s and 1.39 s respectively. For the Dharamsala earthquake, **Shapur station**, transverse-component (also a fault-normal component) of the recorded velocity time history showed pulse-type ground motion with pulse-period (*Tp*) 0.52 s and pulse-indicator 0.94. Extracted pulse from Fault-Normal component of ground motion at Shapur, Bhatwari and Gopeshwar sites adopting db7 wavelet is shown in Fig. 1. Table 1 provides the details of the pulse-indicators (PI) and pulse-periods (*Tp*) obtained adopting different mother wavelets for fault-normal components at three sites. It is found that due to high **PGV/PGA** ratios, the acceleration-sensitive regions for the **Uttarkashi earthquake** at **Bhatwari station** and the **Chamoli earthquake** at **Gopeshwar station** extends up to 0.65 s and 0.53 s, respectively [16]. These values are higher than the codal value at hard soil (**0.40** s). Response spectra also show much higher spectral amplitudes in the velocity-sensitive region. Epicentres of three Himalayan earthquakes and locations of stations that contain near-fault pulses are shown in Fig. 2. As a consequence of widening of the acceleration-sensitive region, the structures designed according to IS 1893: 2016

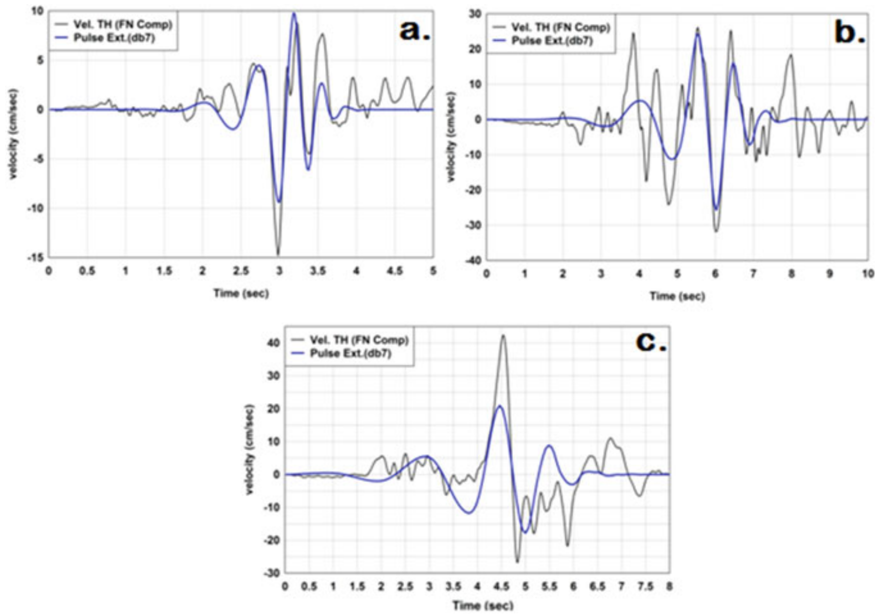


Fig. 1 Fault-Normal component ground motion at **Shapur** (**a**)**, Bhatwari** (**b**) and **Gopeshwar** (**c**) sites along with extracted pulses from velocity time history using **db7 wavelet**

Table 1 Pulse-indicators and pulse-periods using different mother wavelets for Fault-normal components of SGM at Shapur, Bhatwari and Gopeshwar stations

Mother wavelet	Shapur site		Bhatwari site		Gopeshwar site	
	(PI)	Tp (s)	(PI)	Tp (s)	(PI)	Tp (s)
db4	0.9051	0.53	0.9112	1.09	0.9813	1.40
db7	0.9431	0.52	0.9300	1.30	0.9019	1.39
haar	0.7631	0.40	0.5111	0.78	0.9996	1.08
sym4	0.4241	0.59	0.5353	1.04	0.9886	1.37
coif2	0.5692	0.55	0.4941	1.02	0.9624	1.54
rbio2.4	0.6431	0.50	0.5307	1.15	0.9893	1.84
bior1.3	0.8223	0.47	0.3633	0.90	0.9990	1.22

as flexible structures shall behave as stiff structures in the near-fault region in the Himalaya. At Shapur station, the acceleration-sensitive region extends up to 0.35 s. This is slightly lesser than the codal value and also has lower spectral amplitudes compared to codal response spectral amplitudes (IS 1893: 2016). This is attributed to smaller magnitude of Dharamsala earthquake compared to Uttarkashi and Chamoli earthquakes.

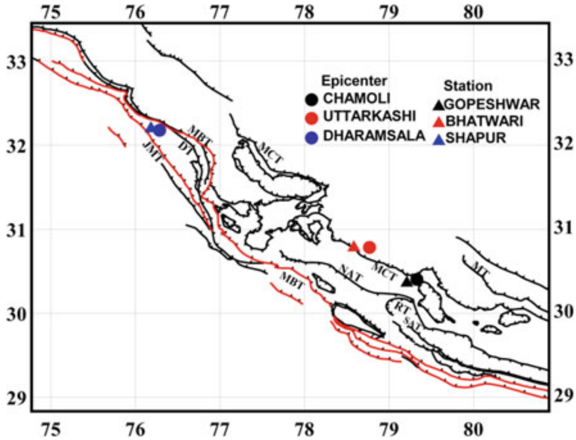


Fig. 2 Epicenters of three earthquakes and locations of stations that contain near-fault pulses

4 Estimation of Ground Motion Including Near-Fault Factor at Bhatwari, Gopeshwar and Shapur Sites

The peak horizontal ground accelerations (PHA), spectral accelerations (Sa) at 5% damping (between 0.01 s and 4.00 s periods) at three selected sites (Shapur, Bhatwari and Gopeshwar) located in the Lesser Himalaya incorporating the NFGM factor have been computed using the methodology given by Division of Engineering Services Geotechnical Services, Caltrans, 2012, for Developing Deterministic Acceleration Response Spectrum [17]. For this purpose NGA relationship given by Boore and Atkinson (2008) applicable for 'M_w' ranging between 5 and 8, $R_{JB} \leq 200$ km and $V_{S30} = 180$–1300 m/s were adopted [18]. For each site, the shortest distance between the site and the rupture surface, called Joyner-Boore distance *(R_{jb}),* for all seismic sources (faults) located within 30 km from the sites were computed using Arc Info GIS 7.2.1D [16]. The highest PHA is taken to represent maximum acceleration due to MCE at each site and corresponding spectral accelerations (Sa) at 5% damping between 0.01 s and 4.00 s with NFGM factor were estimated.

The maximum magnitude associated with each seismotectonic source is estimated from the surface rupture length adopting the general assumption that 1/3 to 1/2 of the total length of fault would rupture producing the maximum earthquake [19]. Using the relation, $Mw = 5.00 + 1.22\log(L)$, between the surface rupture length (L) and earthquake magnitude (Mw) for reverse fault; the Mw for each seismotectonic source is estimated and, the rupture width (RW) for each seismotectonic source is calculated from the relation, $\text{Log}(RW) = -1.01 + 0.32\,Mw$ [20]. In the calculation of R_{jb} distances, the dip-angle (α) is taken as 15° because most of the seismotectonic sources in the Himalayas are thrust types. The maximum value of PHA computed at three sites, along with seismotectonic sources/faults that have made maximum contribution are listed in Table 2. Six response spectra for the **Gopeshwar site** that falls in Zone V as per Indian seismic code, IS 1893: 2016 [21] are shown in Fig. 3.

Table 2 Computed peak horizontal accelerations (Ah (g)) at three selected sites along with location and source that has made maximum contribution

Site	Lat (°)	Long (°)	PGA (g)	Source, reverse fault type, $M_{w(\max)}$
Shapur (SS1)	32.217	76.183	**0.50**	Jwala Mukhi Thrust (**JMT**),7.4
Bhatwari (SS2)	30.810	78.610	**0.58**	Main Central Thrust (**MCT**), 7.8
Gopeshwar (SS3)	30.667	79.550	**0.51**	Main Central Thrust (**MCT**), 7.8

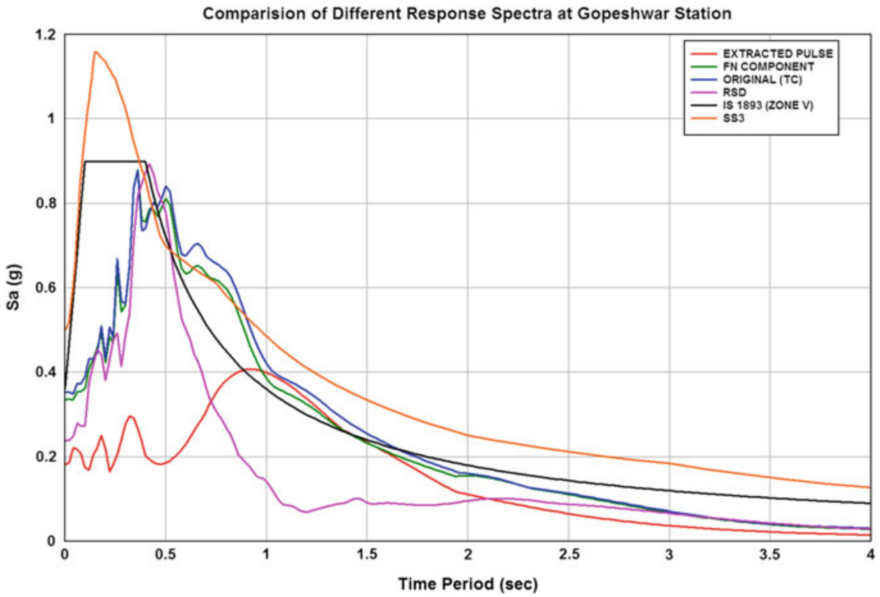
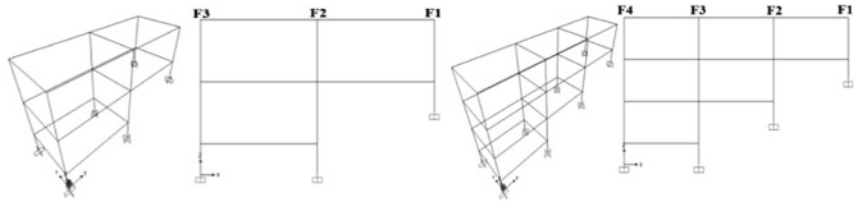


Fig. 3 Response spectra(s) of SSGM, original GM (TC), FN component, extracted pulse and residual (RSD) at Gopeshwar site and codal spectra (IS: 1893:2016)

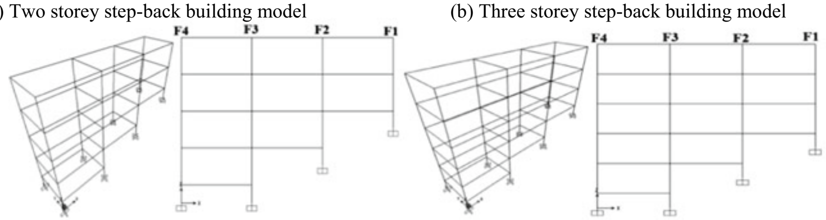
The response spectra are: (i) Site-specific response spectra (**SS3**), (ii) Spectra due to recorded pulse-type ground motion (transverse-component (**TC**)), (iii) Spectra of fault-normal (**FN**) component, (iv) Spectra due to extracted pulse ground motion (**EXT**), (v) Spectra due to residual (**RSD**)/high-frequency part of fault-normal (**FN**) component and (vi) Codal spectra for Zone V as per Indian seismic code**.**

5 Dynamic Analysis of Hill-Slope Buildings

The buildings resting on sloping ground, generally existing in hilly areas, usually have a step-back (SB) configuration or a combination of step-back and set-back (SBSB) configuration as shown in Fig. 4. These models are selected because most of the residential buildings in the hilly regions are low-rise buildings with number of

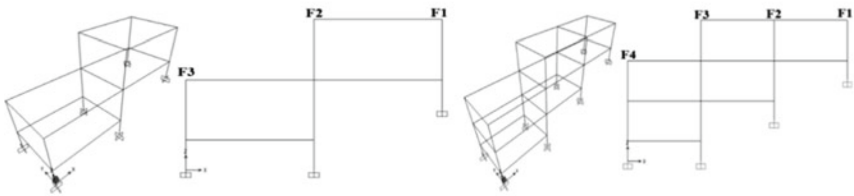


(a) Two storey step-back building model (b) Three storey step-back building model

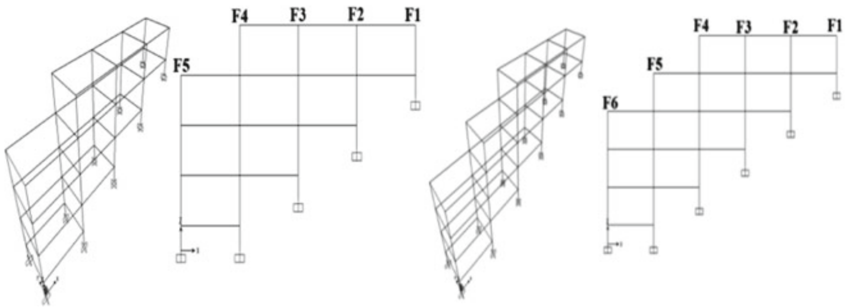


(c) Four storey step-back building model (d) Five storey step-back building model

(a) 212SB (b) 313SB (c) 413SB (d) 513SB Step-Back (SB) building models



(a) Two storey step-back-set-back building model (b) Three storey step-back-set-back building model



(c) Four storey step-back-set-back building model (d) Five storey step-back-set-back building model

(a) 212SBSB, (b) 313SBSB (c) 414SBSB (d) 515SBSB Step-Back-Set-Back (SBSB) building models

Fig. 4 Step-Back (SB) and Step-Back-Set-Back (SBSB) building models

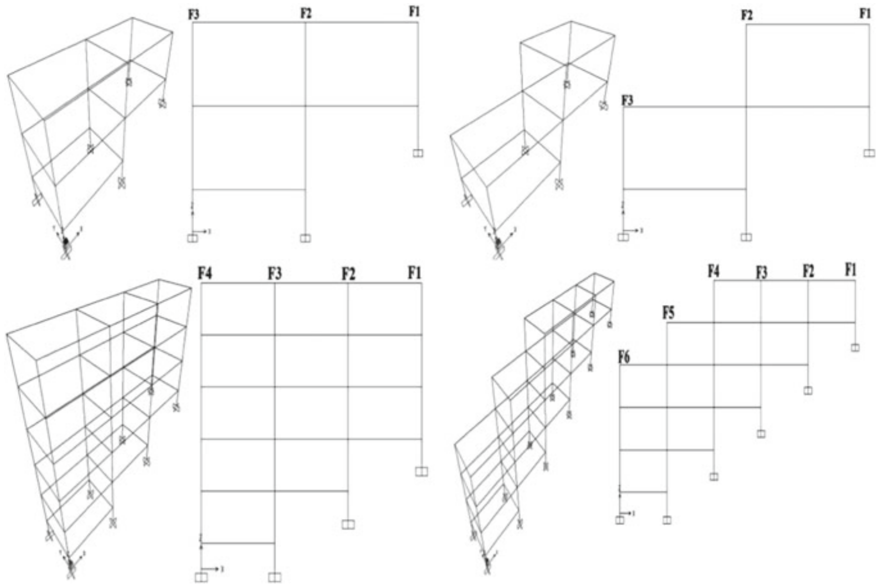
storeys limited to five storeys in majority of cases. For both types of building models, the number of storeys has been varied from two to five.

Responses of R.C. framed buildings (Step-Back (**SB**) buildings and Step-Back-Set-Back (**SBSB**) buildings) on hill-slopes subjected to NFGMs are analyzed. From seismic safety point of view responses due to NFGMs are compared with the response obtained from conventional types of inputs. Earthquake response of buildings on hill-slope depends upon the distribution of mass and stiffness, both of which vary in the horizontal and vertical plane. For Step-Back (SB) buildings, various floor levels step back towards the hill slope keeping the top floor level same for all the bays. In case the building has set-back, then the building is called a Step-Back-Set-Back (SBSB) building [22]. Both types of buildings have columns of different heights at ground level, due to which the shorter columns attract more force as these are stiffer. The Indian seismic code recommends the dynamic analysis of such irregular structures. Eight special moments resistant frame (**SMRF**) building models, four SB and four SBSB (Fig. 4), models are analyzed in SAP2000. For both types of building models, the number of storeys varies from two to five.

The slope of the ground is taken as 27° with horizontal which is neither too steep nor too flat and also considered during many past studies [23–28]. The structural material is assumed to be isotropic and homogenous. Joint between the building elements (beams and columns) are modelled by using diaphragms as constraints. The dynamic analysis (Response Spectrum Analysis) of buildings is carried out for rigid base (fixed-base) laid on rock site conditions in longitudinal (along the slope, X) and transverse direction (across the slope, Y). The dynamic analyses of all the buildings were carried out adopting.

(i) Response Spectrum Method (according to **IS**: 1893 (Part 1)), (ii) Response Spectra obtained by NFGMs along with their extracted pulses (**EXT**) and residual components (**RSD**) and iii) Response Spectra obtained by site-specific ground motion (**SSGM**) at three sites (**SS1, SS2 and SS3**). Damping considered for all structural modes of vibration is five percent (5%). The computed results are expressed in terms of two parameters: floor displacements (horizontal) and shear forces in ground columns. Since the buildings are on the sloping ground, there should be short column-long column effect which could be major cause of structural failure. At Gopeshwar site, the results obtained on the dynamic structural response of two and five storey buildings (Fig. 5) are presented in Figs. 6, 7, 8 and 9. These results are discussed below on the trend basis considering various types of ground motions at the selected site. In the figures and texts, symbols XX, YX and YY stand for, seismic input in X, Y, Y directions and computed parameters in X, X, Y directions respectively.

Properties of considered building configurations and intensity of loads imposed on them are summarized as, Height of each floor: 3.5 m, Plan dimension of each storey block: 7 m × 5 m, Slab thickness: 0.15 m, Wall thickness: 230 mm, Parapet wall thickness: 230 mm, Density of concrete: 25 KN/m^3, Poisson's Ratio: 0.2, Damping: 0.05, Size of column: 230 mm x 500 mm, Size of beams: 230 mm x 500 mm, Material properties, M 25 & Fe 415, Slab dead—3.75 KN/m^2, Floor Live load—3 KN/m^2, Roof Live load—1.5 KN/m^2, Floor Finish—1 KN/m^2, Roof Finish—1.5 KN/m^2, Exterior Wall Load—16.15 KN/m, Interior Wall Load—10.5 KN/m, Parapet wall load—6.9 KN/m.



212SB & 513SB buildings **212SBSB & 515SBSB buildings**

Fig. 5 Step-Back (**SB**) and Step-Back-Set-Back (**SBSB**) buildings (two and five storey buildings)

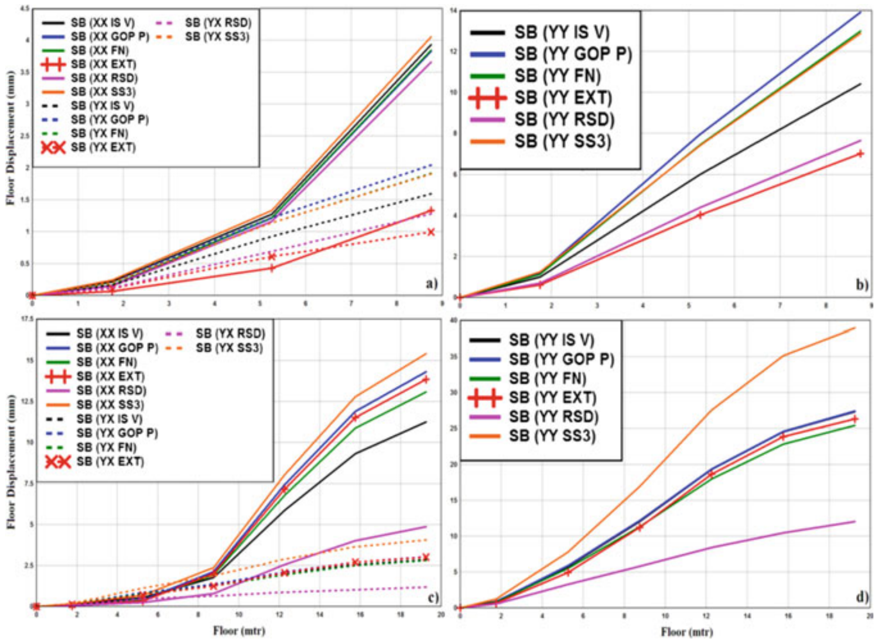


Fig. 6 Floor displacements (FD) of two (**a**, **b**) and five (**c**, **d**) storey Step-Back (212SB & 513SB) buildings

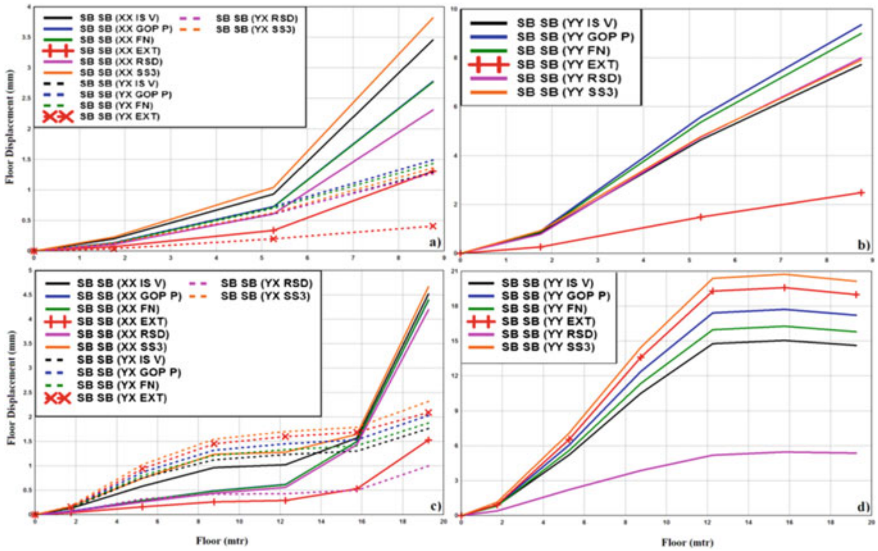


Fig. 7 Floor Displacements (FD) of two (**a, b**) and five (**c**, **d**) storey Step-Back-Set-Back (212SBSB & 515SBSB) buildings

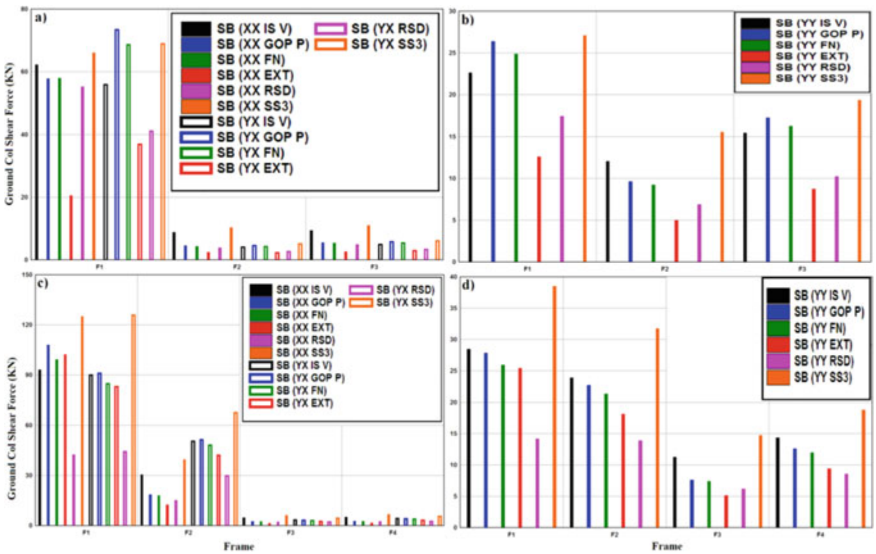


Fig. 8 Ground column shear force (GCSF) of two (**a, b**) and five (**c**, **d**) storey Step-Back (212SB & 513SB) buildings

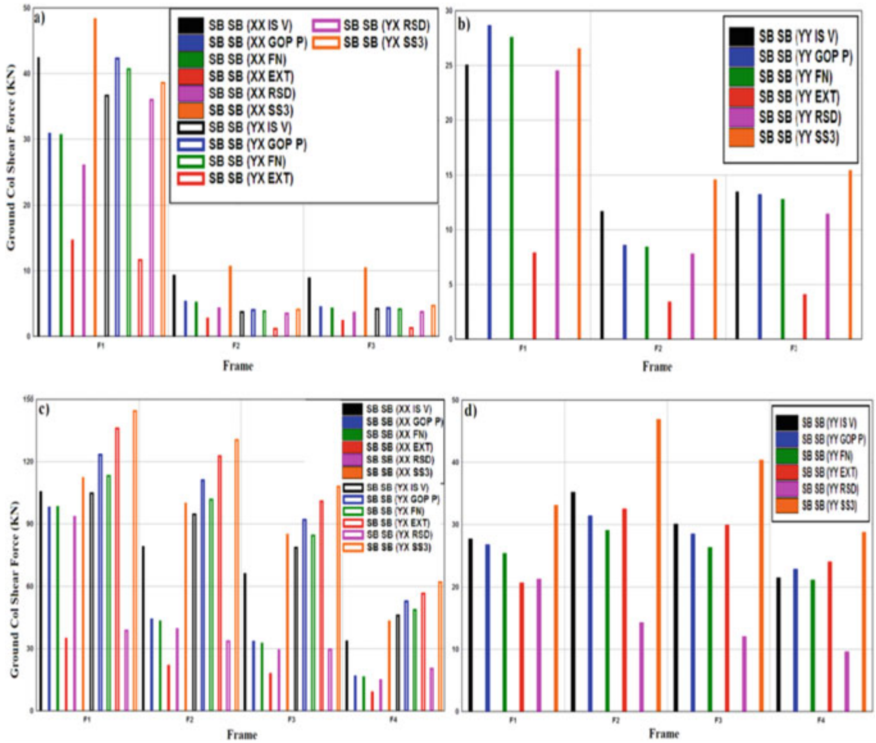


Fig. 9 Ground column shear force (GCSF) of two (**a**, **b**) and five (**c**, **d**) storey Step-Back-Set-Back (212SBSB & 515SBSB) buildings

6 Floor Displacement (FD) of 212SB & 513SB Building Models Along (X-Dir) and Across (Y-Dir) the Slope

In the figures and texts, symbols XX, YX and YY stand for, seismic input in X, Y, Y directions and computed parameters in X, X, Y directions respectively.

XX: Floor displacement in the X-direction (Fig. 6), for both types of building models subjected to SSGM (SS3), is higher than other seismic inputs. For 212SB, the FD due to residual part of the fault-normal (FN) component is much higher compared to FD due to extracted GM pulse. This is because the residual part of the GM is composed of high frequencies and natural time period of such a building is small. However, in case of 513SB, the FD due to extracted GM pulse shows significantly higher values compared to residual GM because of low frequency nature of extracted pulse and comparatively longer-period of structure.

YX: For 212SB model, Floor displacement (FD) in X-direction due to application of extracted GM pulse in the Y-direction has brought out comparatively higher values of FD at intermediate floors compared to "XX-EXT" shown in Fig. 6. However, for 513SB the effect of torsion (YX) is seen to be very less at all floor levels.

***YY*:** For 513SB model, the FD in the Y-direction due to application of pulse-extracted GM in the Y-direction is almost comparable to that computed from the original recorded GM (transverse-component), FN component and codal spectrum. However, FD at all floor levels due to SSGM is much higher and residual part of the GM is much lower as compared to FD due to other seismic inputs (Fig. 6). For short-period structure (212SB) the effect of extracted pulse is found to be least.

7 Floor Displacement (FD) of 212SBSB & 515SBSB Building Models Along (X-Dir) and Across (Y-Dir) the Slope

In the figures and texts, symbols XX, YX and YY stand for, seismic input in X, Y, Y directions and computed parameters in X, X, Y directions respectively.

***XX & YX*:** For both the building models, along the slope (X-direction) the maximum FD (XX) is obtained due to SSGM as compared to other seismic inputs (Fig. 7). This displacement is closer to that computed from codal spectra. Further, it is seen that for both models the FD (XX) due to residual part is higher than that computed from extracted GM pulse. This is because, in the X-direction, there is no significant change in the time period of the buildings. These displacements are in X-direction when the seismic inputs are applied in the X-direction. However, for 515SBSB model, floor displacements (FDs-YX) in the X-direction due to torsion effect (when the GM in Y-direction) is more significant at all intermediate floor levels for all types of GMs. The computed FDs (YX) due to extracted pulse GM is maximum at all floor levels and are comparable to SSGM, whereas the FD (YX) because of residual part of the GM is lowest at all floor levels.

***YY*:** For 212SBSB model, floor displacements in the Y-direction due to residual part are seen to be much closer to displacement due to SSGM, codal spectra and much higher as compared to EXT pulse GM shown in Fig. 7. Whereas, in 515SBSB model, the FD due to the residual part of GM is much lower than all types of GMs. Further, the response due to EXT pulse GM and SSGM are comparable.

8 Ground Column Shear Force of 212SB & 513SB Building Models Along (X-Dir) and Across (Y-Dir) the Slope

In the figures and texts, symbols XX, YX and YY stand for, seismic input in X, Y, Y directions and computed parameters in X, X, Y directions respectively.

XX: For step-back building models (212SB & 513SB), because of short column effect, the shear force in columns at ground level in frame 'F1' attracts a much higher force in both directions as compared to other frames (Fig. 8). Comparison of responses between 212SB & 513SB has brought out that in 212SB the response due to residual part of FN component of GM is much higher (about three times) than the EXT pulse GM response. Because of the long-period, the response of 513SB due to original GM, FN component of GM and extracted pulse (EXT) GM exceeds the codal response. Response due to SSGM shows significantly higher values than all types of GMs for both the models because of high value of PGA.

YX: The application of seismic input in the Y-direction (across the slope) has shown that shear force in ground columns in X-direction (along the slope) due to torsional effect are equally important as they exceed non-torsional response for some GMs in 212SB. However, for 513SB the torsional and non-torsional responses are comparable. The torsional response due to extracted pulse GM in 513SB exceeds the residual response and is much closer to the response due to FN component of GM and original ground motion (OGM) in frames 'F1' and 'F2'. The shear force (SF) due to recorded ground motion (GOP P, transverse-component) and FN component of GM in 'F1' shows higher values compared to SSGM in 212SB (Fig. 8).

YY: The application of seismic input across the slope (Y-direction) has brought out that the shear force (Y-direction) due to SSGM is higher in ground columns of all frames for both 513SB and 212SB models. The response due to residual GM is more than the extracted pulse GM in all the frames (F1, F2 and F3) of 212SB building model but lower than the response due to extracted (EXT) pulse GM in 'F1' and 'F2' of 513SB (Fig. 8).

9 Ground Column Shear Force of 212SBSB & 515SBSB Building Models Along (X-Dir) and Across (Y-Dir) the Slope

In the figures and texts, symbols XX, YX and YY stand for, seismic input in X, Y, Y directions and computed parameters in X, X, Y directions respectively.

XX: For both Step-Back-Set-Back (SBSB) models 'XX' component of shear force shows higher response because of residual part of GM as compared to EXT pulse GM in building frames. Further, response due to residual GM is closer to response due to recorded transverse-component of GM and FN component of GM for both the models but lower than response due to IS codal spectra (**Fig. 9**). However, the response due to SSGM is highest.

YX: It is brought out that the effect of torsion is significant in 515SBSB model as torsional component (YX) due to all types of seismic inputs (GMs) exceeding respective 'XX' component (non-torsional response) in all building frames except response due to residual GM. The response (YX) due to torsional effect of extracted pulse GM has exceeded significantly the response due to residual part of FN (GM) in all frames of 515SBSB model. This response also exceeds the codal, recorded, FN component response and is closer to SSGM (Fig. 9). Further, it is observed that torsion effect is significant in frame 'F1' as compared to other frames in 212SBSB model and response due to residual part of GM exceeds the response due to extracted pulse GM and is closer to response due to other GMs at the selected site (Gopeshwar).

YY: When the seismic inputs or excitations are in Y-direction, higher response (Y-direction) is observed due to residual part of FN-GM in 212SBSB model. This response is almost comparable with the response due to codal spectra, original GM, FN component and SSGM. Further, this response is significantly higher than the response due to extracted pulse GM in all the building frames (Fig. 9). However, in 515SBSB model, higher response is observed due to extracted pulse of FN ground motion compared to residual GM in all building frames.

10 Conclusions

Response of two types of building models (SB and SBSB) have brought out that as the number of storeys increases from 2 to 5, the extracted pulse response increases compared to response due to residual component GM; because as the height of the building increases the time period also increases resulting in decrease of high-frequency response. This is only true when the seismic inputs are across the slope (Y-direction) and direction of displacements is observed in the in-plane (X) and out-of-plane (Y) directions. However, for 2–4 storey "SBSB" buildings, the response due to the residual component is always higher than the EXT pulse response when the GM is applied in X-direction (along the slope) because there is no significant variation in the time periods of the models in X-direction. For similar types of earthquake loadings, the five story building (SBSB) the response due to EXT pulse GM is higher compared to RSD response.

With the increasing period of buildings, response due to extracted long-period pulse at three sites is in close agreement with responses due to recorded pulse-type ground motions & FN component of ground motions. This illustrates the adequacy of representation of NFGM with extracted long-period pulse. The Indian codal spectra need modification and the effects of pulse-type ground motion due to moderate, large, and great earthquakes should be incorporated for sites in the vicinity of near-fault regions particularly for the Himalayas region. However, for earthquakes with Mw $\leq$ 6, like the 1986 Dharamsala earthquake, the Indian seismic code is found to be adequate.

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Microseismic Monitoring to Analyze Rock Mass Micro-Cracking in Underground Powerhouse to Mitigate Potential Disaster

Vikalp Kumar and V. R. Balasubramaniam

Abstract Rock mass equilibrium is disturbed when rocks undergo excavation through mechanical or blasting techniques. When the disturbance is rapid, it leads to unstable zones in the structure even after completion of structure in long term, and hence it becomes essential to monitor such underground excavated structure behavior continuously using microseismic monitoring. Microseismic Monitoring (MSM) is an effective technique to locate zones of micro-cracking in the rock mass and further for the demarcation of potentially unstable zones in underground excavation. This paper gives a brief account of the Microseismic Monitoring System that has been applied in the underground powerhouse of Tala Hydropower Plant (THP). Stability of the underground powerhouse was analyzed using various microseismic source parameters. Based on one-year of continuous monitoring, potential unstable zones were identified at the powerhouse of THP. Microseismic Monitoring System thus provides information ahead and helps audit the safety measures taken at any site. Therefore, this technique is an effective way to evaluate rock mass behavior before occurrence of any disaster and helps to diminish the potential damages.

Keywords Microseismic monitoring · Underground powerhouse · THP · Stability and disaster

1 Introduction

Keeping the underground excavated geo-structure safe and stable under different rockmass conditions is required for smoother operations of the intended activities. To maintain long-term stability and integrity of underground structures, such as powerhouse with valuable machinery and sustain the operations after the construction of the structure, is a challenge for any geotechnical professional. Such underground powerhouse structure has the risk of collapse, wall caving and rock burst. Due to the complex nature of rock mass, internal partial damage in rock mass may trigger

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a series of chain damage, and which results in large-scale deformation and collapse of the structure fully or a portion there [1].

Rock masses are anisotropic and heterogenous material. Rock mass failure might be induced by the propagation of internal non-visible micro-cracks and further its coalescence. Propagation of these micro-cracks in underground excavated rockmass structure is a dynamic phenomenon. These micro-cracks may develop with time and space [2, 3] and finally the surface may collapse with large-scale rock mass deformation.

Traditional or conventional monitoring techniques that consist of equipments like convergence meter, surface subsidence monitoring, extensometer, load cell, Global Positioning System, etc. are effective to monitor the deformation of rock mass surface [4]. However, it is difficult for these equipments to effectively monitor the occurrences of micro-cracks inside the rock mass prior to the formation of a macroscopic rock fracture that may sometimes result in the detachment or loosening from the host medium, and eventually become unstable which may lead to a probable disaster.

The beginning, buildup and evolution of stress-induced micro-cracks release energy as seismic signals from the rock mass which are under stress in and around the opening of the underground excavations.

Occurrence of seismic signals releases energy that propagates in the form of P and S waves in the rockmass (Fig. 1) [5]. Longitudinal (P) and transverse (S) wave propagation patterns are demonstrated by the respective red/blue and green/yellow contours.

Microseismic monitoring system can transform the received seismic signal into electrical signals using geophones and/or accelerometers. Microseismic data processing and analysis techniques are used further to calculate the time (t), location (x, y and z) and local magnitude (m_L) of micro-cracking events in three-dimensional

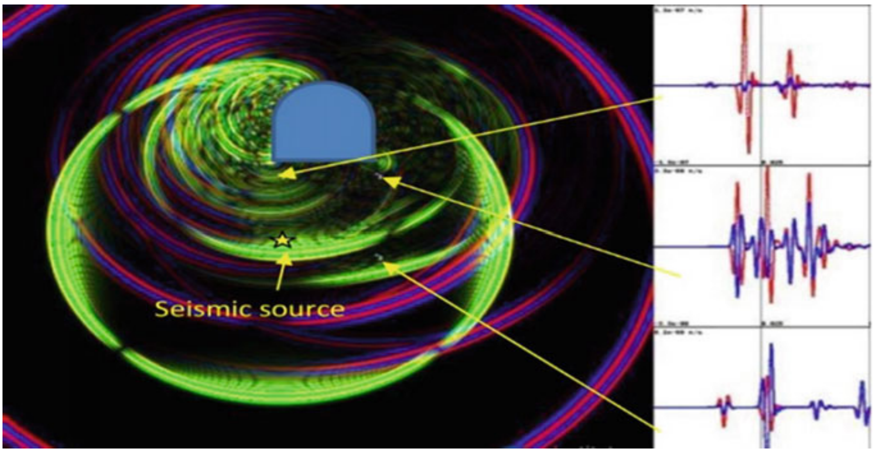

Fig. 1 Micro-cracking generates ground motion contours with synthetic wave forms for three sensors located below excavation

space, in addition to a host of seismic source parameters. Further the range (time, distance) of probable development of micro-cracks may be evaluated.

Microseismic signatures inside a rock mass are passive indicator of the progress of inelastic damage with time in a particular zone [6]. This method is viable and non-destructive to detect micro-cracks prior to a macroscopic rock mass failure. Incorporation of localized microseismic events with its seismic source parameter is used to visualize and provide status of a particular zone in three-dimensional space.

Microseismic Monitoring (MSM) technique is now a days being applied mainly in mining, underground powerhouse, dam, oil and gas storage cavern, hydraulic fracturing, etc. This method can also be used to prevent illegal mining by providing the three-dimensional spatial coordinates in real time in and around the government approved mining license areas to various stakeholders.

The site of investigation using MSM is THP underground powerhouse of Druk Green Power Corporation (DGPC) Ltd. (6*170 MW) located in Chukka, Bhutan. This underground powerhouse structure has an overburden rock mass of 500 m thickness on an average. It has encountered several rock engineering issues since construction, and which is continuing even during the power generation stage. Several incidences of rock mass failures occurred during its construction [7, 8]. There are reports of rock bolt failures in an irregular manner and risk to life of the working personnel and machine components at the site. The cavern's wall are also converging at a slow rate [9, 10]. Therefore, there is always an induced threat prevailing inherently in this structure and thus there is always a need to analyze the stress, displacements, etc. in various zones of this structure. National Institute of Rock Mechanics (NIRM) in collaboration with the Institute of Mines Seismology (IMS), Australia and DGPC ltd. has set up Microseismic Monitoring System at THP powerhouse to monitor and evaluate the powerhouse stability status.

2 Microseismic Monitoring System at Tala Hydropower Plant

THP powerhouse consists mainly of main access tunnel, powerhouse chamber (machine hall), transformer hall, bus ducts (3 numbers), connecting tunnel, escape tunnel and drainage gallery (Fig. 2) (Table 1).

Reconnaissance survey was conducted to identify sensor locations, energy attenuation characteristics, noise sources, longitudinal (P) and transverse (S) wave velocities [11]. Hammer tests were performed at a number of locations inside this underground rockmass cavern to find out the P and S wave velocities, signal attenuation from the recorded seismogram. P and S wave velocities obtained from the seismogram were 4500 m/s and 2600 m/s, respectively. At the same time, geological and modeling reports were studied which state that most of the failure in the rockmass

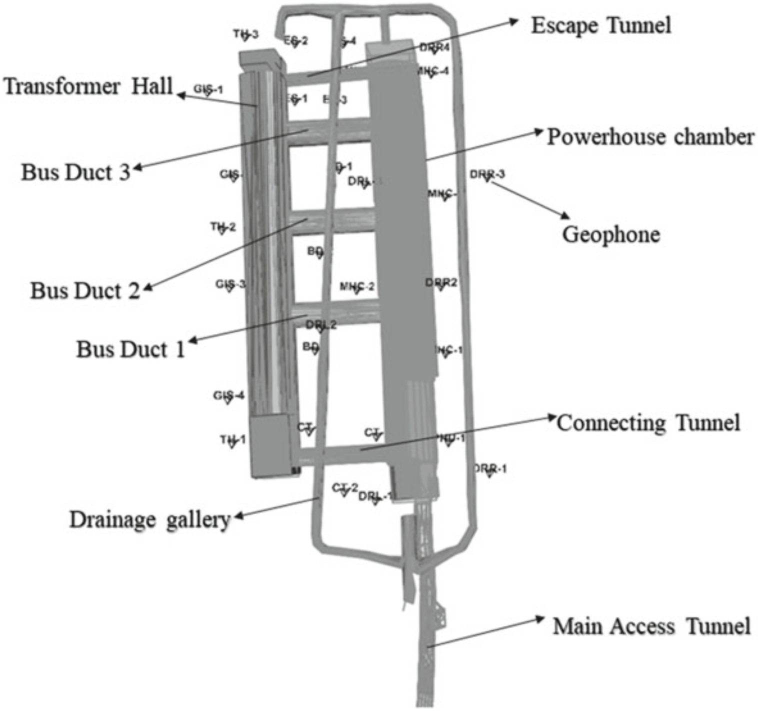

Fig. 2 Major tunnels of THP powerhouse with thirty installed geophones

Table 1 Major Tunnel dimension in the underground powerhouse of THP

S. No.	Name of the tunnel	Length (in m)	Width (in m)	Height (in m)
1	Main access tunnel	377	7.5	8
2	Powerhouse chamber	206	20.4	44.5
3	Transformer hall	191	16	26.5
4	Connecting tunnel	39.4	10	8.5
5	Escape tunnel	39.4	3	3
6	Bus ducts	39.4	10	8.5
7	Drainage gallery	590	3	4

occurred in machine hall during construction. Based on these data, an optimum three-dimensional microseismic monitoring network was installed to record, process and interpret waveforms generated in the underground powerhouse.

This network mainly consists of thirty geophones (installed at various locations inside the powerhouse), eight data acquisition units and underground laboratory (Fig. 3). Underground laboratory consists of central data recording server (CDRS) having duplex communication facility and central communication hub.

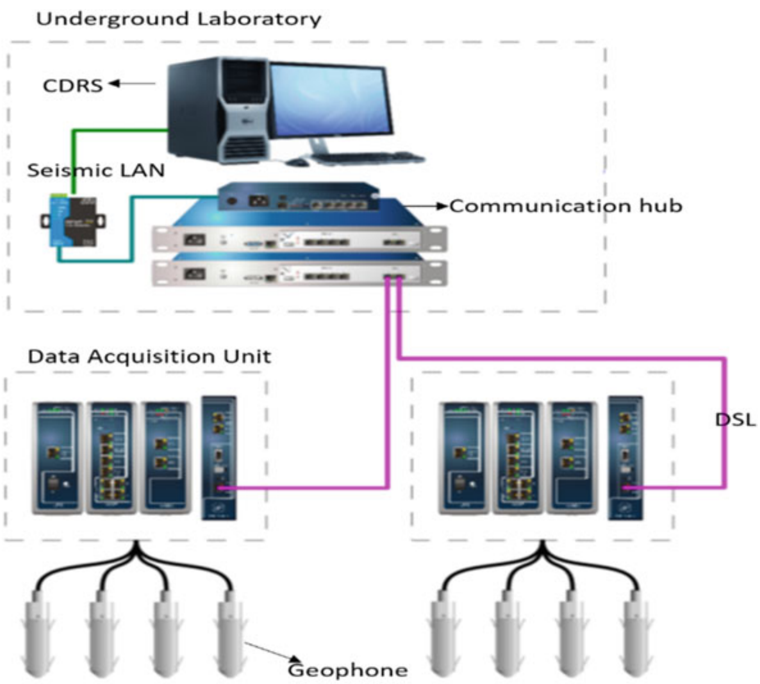

Fig. 3 Microseismic monitoring Network at THP

CDRS acquires and stores the waveforms in triggered mode. The signals from the sensors recorded are shown in Fig. 4. Source parameters of this microseismic signal, shown in Fig. 5, are of the event that occurred on 09 January 2018 at 15:26:11 h. and having local magnitude −2.3. The network consists of 30 sensors but signal was

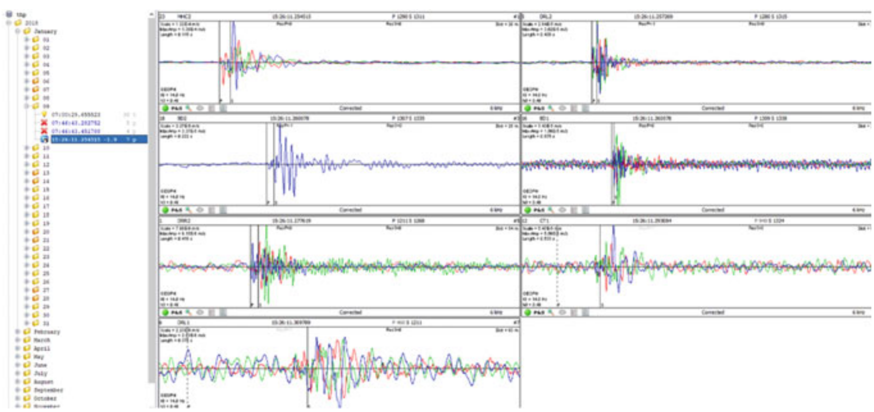

Fig. 4 Microseismic signal recorded by seven geophones

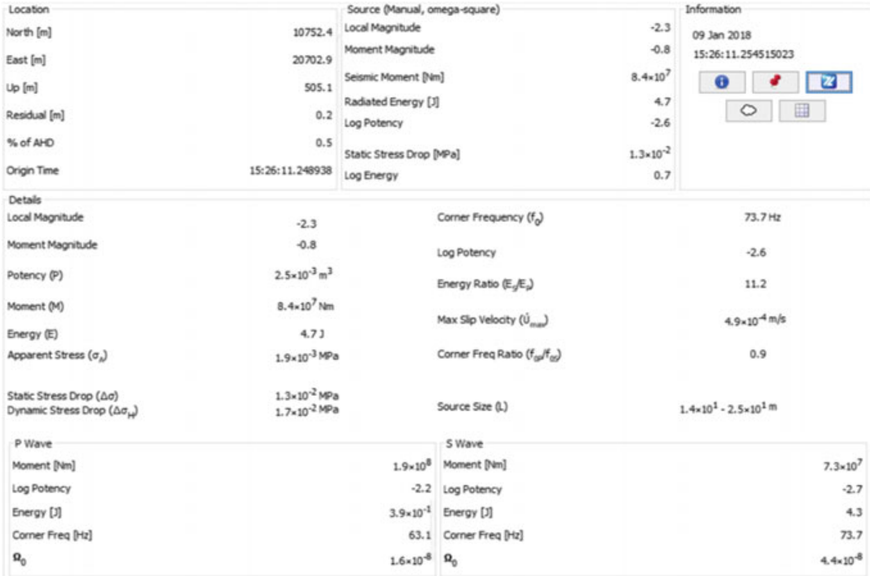

Fig. 5 Source parameters of the microseismic signal (09 January 2018, 15:26:11 h)

recorded by only seven sensors as only a low seismic energy of 4.7 J was liberated due to this microseismic event.

3 Microseismic Data Processing and Analysis

Various types of triggering waveforms at underground powerhouse cavern THP were recorded during one-year continuous monitoring from 01 January 2018 to 31 December 2018 which consist of microseismic events and noises. Major sources of noise are compressor signal, earthquake, electric circuit breaker and man-made activity at the underground powerhouse cavern (Fig. 6). The pattern of noise has been analyzed and established and further such waveforms which do not conform to the criteria of rockmass behavior related signals have been eliminated. After processing and analysis, only 130 triggers were accepted as microseismic events. These events were then mapped on 3D diagram of THP powerhouse (Fig. 7).

The average number of events amounted to 11 events per month. Local magnitude of the microseismic events ranged from −2.8 to 0. Radiated seismic energy of these microseismic events varied from 0.63 to 15,848 J. Maximum source location error was 3% having absolute error margin of 5 m. This microseismic monitoring network at THP enabled timely and periodic evaluation of rock mass status in and around this powerhouse. Given the geometry of the microseismic monitoring network in this

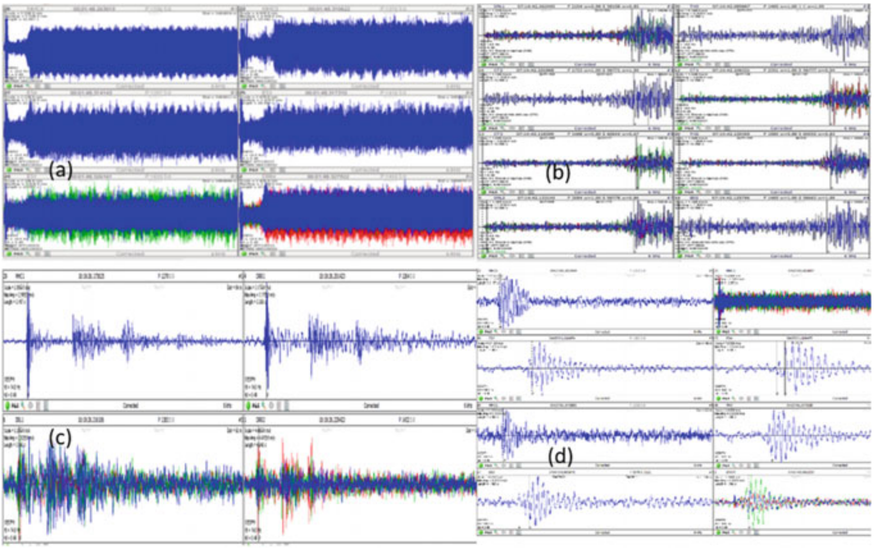

Fig. 6 Types of noises: **a** compressor signature, **b** micro-earthquake, **c** hammering noise and **d** electrical signature (50 Hz)

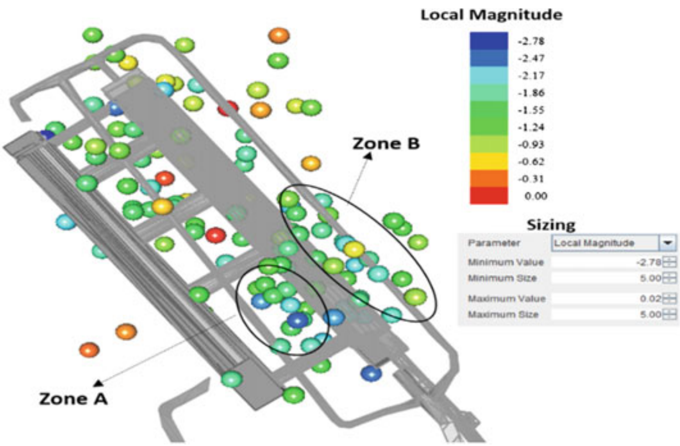

Fig. 7 Microseismic events on 3D layout of the powerhouse

underground powerhouse cavern, formation of cluster of microseismic events point out the micro-cracking zone inside the rockmass [12].

4 Stability Status of THP Powerhouse Cavern

Most of the events have occurred in and around the powerhouse chamber in comparison to the transformer hall (Fig. 7). Thus, machine hall seems to be seismically more active than the transformer hall. Further evaluation of microseismic events in the machine hall states that there are two major cluster of events namely zone A and B as follows: (a) between connecting tunnel and bus duct-1 and (b) from RD 20–100 m in the machine hall upstream wall. Microseismic events distribution pattern as per size in THP powerhouse during one year of continuous monitoring may be expressed by the relationship as follows [13] (Fig. 8):

$$\log_{10} N = a - b \quad (1)$$

where N = cumulative number of microseismic events having local magnitude $\geq M$, a and b are constants that may be derived from the respective offset and gradient of the straight-line plot between $\log_{10} N$ and local magnitude M.

The parameter 'b-value' technically defines the relative number of large to small number of seismic events and 'a-value' describes productivity. Thus, the parameter b is a measurement of seismic environment in THP powerhouse and defines the probable pattern of seismicity in that region like stress build-up pattern. Standard value of parameter 'b' varies from 0.8 to 1.1 with a notional value of 1. Higher b-value signifies more occurrences of low energy microseismic events, whereas low

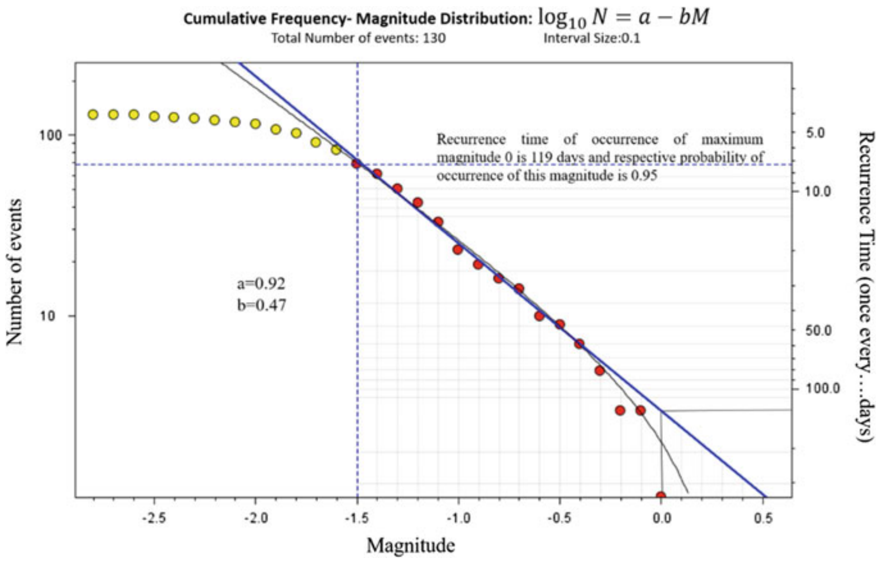

Fig. 8 Gutenberg Richter relationship for tala hydropower plant powerhouse cavern

value of the parameter ‘b’ may be implied as high magnitude microseismic events are dominant [14].

For this 130 microseismic events over one-year window at the powerhouse of THP, the respective obtained values of ‘a’ and ‘b’ are 0.92 and 0.47. As the b-value is toward higher side. So, it indicates that production of low energy (low magnitude) microseismic events are more at THP powerhouse. By using the same plot (Fig. 8), the recurrence of a particular value of local magnitude of seismic event can be computed by the following equation [15, 16]:

$$Tr \geq m = \Delta t / N(\geq m) \tag{2}$$

where Δt = monitoring period and
$N(\geq m)$ = number of seismic events.

At THP, maximum magnitude of microseismic event is 0. Using Eq. (2), for an event of this maximum magnitude 0 that occurred during this one year window, recurrence time is 119 days. Probability of this maximum local magnitude microseismic event occurrence in one year is 0.95 at this underground powerhouse.

Maximum log (apparent stress) is 3.58 (Fig. 9). As the figure depicts that maximum stress is coming from just outside the underground powerhouse cavern and it is more on the upstream wall of the powerhouse chamber compared to the other major tunnels of this powerhouse cavern. It might be the reason that machine hall is seismically more active than transformer hall and that results more micro-cracks in and around

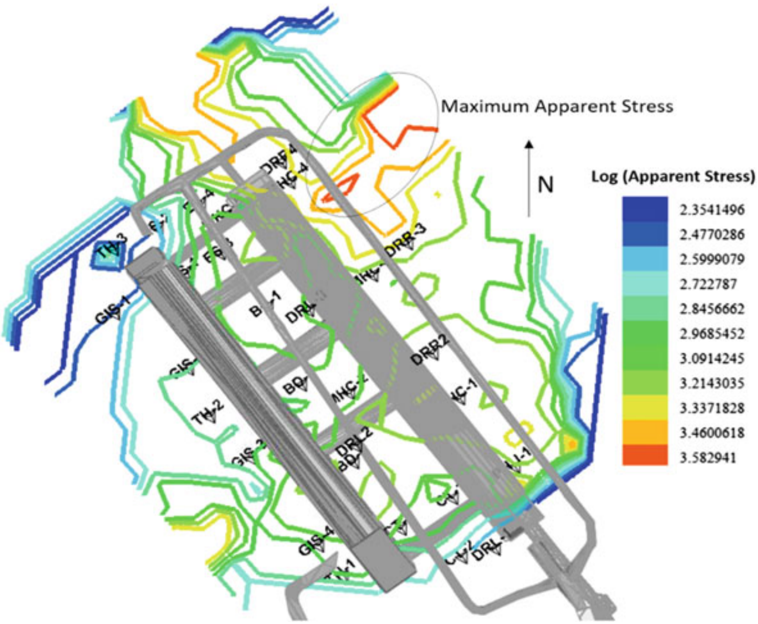

Fig. 9 Log (Apparent Stress) at THP powerhouse cavern

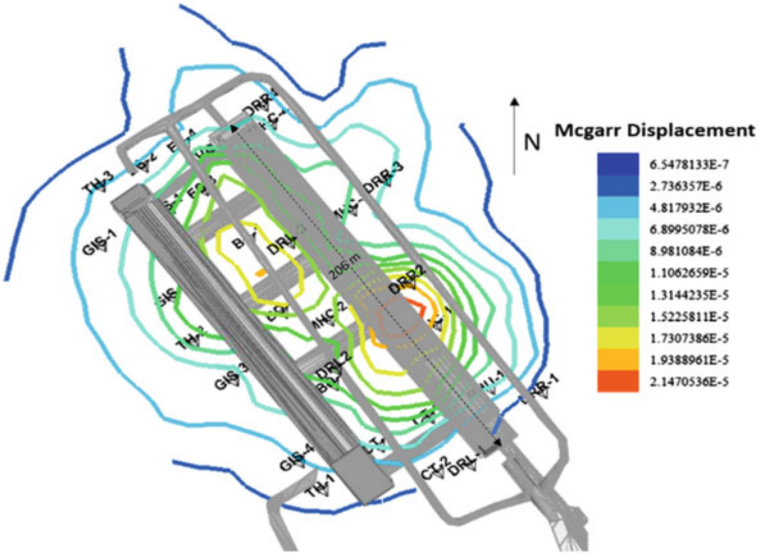

Fig. 10 Mcgarr Displacement at THP underground powerhouse cavern

the machine hall. It also depicts that if one compares both the walls of the machine hall, upstream wall is under more stress than downstream wall.

Mcgarr displacement is linked with seismic events that have average slip D over a smaller fault zone. Small scale seismic moment corresponding to the asperity failure is expressed by Mcgarr [17] (Fig. 10).

$$D = M/(\mu \pi r^2) \tag{3}$$

where M, μ and r are seismic moment, shear modulus and source radius respectively.

Maximum Mcgarr Displacement is in the upstream wall opposite to bus duct-1 (RD: 70–90 m). This is due to the occurrences of more number of microseismic events in Zone-B in comparison to other areas of the powerhouse.

Thus, Zone A and B need proper rock mass reinforcement and support system in THP underground powerhouse. Therefore, these various microseismic source parameters provide the timely assessment of this underground powerhouse stability status and prevent to mitigate any potential disaster.

5 Conclusions

Rock Engineering and Rock Mechanics problems are increasing in various infrastructure projects for the requirement of the mankind especially in the Himalayan region of Indian subcontinent. This study using the principle of microseismic monitoring provides stability status of one underground powerhouse rockmass cavern of THP hydropower project in Bhutan. As there is an occurrence of minor cracks inside the rockmass, it is evaluated to forewarn any disaster in terms of rockmass failure by using the microseismic system. This network at THP provides 3-D picture of micro-cracking propagation with time.

Out of all the recorded waveforms, only 130 waveforms are genuine microseismic events. There are two zones of microseismic events accumulation and both are in the machine hall but these have not been converted into any failure as the rate of events and number of microseismic events are significantly low but indicate for the required reinforcement/support measures to be taken timely. Rockmass strata of this powerhouse appears to be stable on the basis of microseismic source parameters evaluation but it required continuous monitoring to prevent any disaster at the site.

Acknowledgements This study is established on the Microseismic monitoring study done at THP, Bhutan. Thanks are also due to the Director, National Institute of Rock Mechanics for the support and consent to publish this work. Authors are also grateful to Mr. Sivakumar Cherukuri (Ex-Scientist, NIRM) and to the management of DGPC Ltd. Support of Mr. Karma (Head, I & MU, THP, DGPC ltd.) is also acknowledged during this study to arrange the required site literature, installation of microseismic monitoring equipment and other various support. The help of the colleagues of NIRM is also acknowledged. Dr. Iram Saba Amin is also thanked for proofreading and editing.

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Stability Analysis of a Debris Slope by Micropile Reinforcement Technique: A Case Study from the North-Western Himalayas

Koushik Pandit, Mahendra Singh, and Jagdish Prasad Sahoo

Abstract Debris slides take place when a mass of soil or debris slides down over a slip or failure surface. Mitigation or control of such sliding mass frequently poses an engineering challenge. Micropiles are many a times used to stabilize a slope under certain circumstances. To analyze the effect of micropiles on slope stability, one requires to determine the geo-mechanical properties of the strata, slope geometry, micropile diameter, lengths, and locations of such installations. Hence, it becomes a complex interaction problem. In the present study, an active landslide in Tehri Garhwal district of Uttarakhand state of India has been chosen for demonstration of micropile reinforcement technique. After characterization of the slope material, factor of safety of the untreated slope under different degree of saturation have been evaluated by utilizing different limit equilibrium methods for static and pseudo-static conditions. Since the failure surfaces for all the simulated scenarios have been obtained at deeper depths, it was fathomed that deep-seated slip movements need to be arrested partially or fully for which slope reinforcement with micropiles will be a good choice. A parametric analysis was conducted to assess stability of the slope with single rows of micropiles with different diameter, spacing, and aspect ratios. The results show that the slope stability improves satisfactorily for certain cases.

Keywords Landslides · Micropile reinforcement · Factor of safety · Pseudo-static analysis · Mitigation

1 Introduction

The construction process of micropiles involve drilling of a small diameter borehole (typically less than 300 mm) followed by insertion of a reinforcement element (steel section like an I-beam or H-section or a single rebar or a reinforcement cage)

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and finally grouting of the borehole (illustrated in Fig. 1). A usual geotechnical drilling equipment is sufficient for drilling a borehole for micropiles since they are designed for a small diameter. This has many inherent advantages such as: (i) negligible disturbance to the nearby existing buildings and soil during construction, (ii) ease to install the micropiles in low headroom areas and in almost all typical ground conditions, (iii) flexibility to install the micropiles at a suitable desired angle for the intended use of the same, (iv) choice of using the same equipment for both installation and grouting. Micropiles have been found to be useful as supporting elements for building foundations in weak soils and as in-situ reinforcements to improve stability of slopes and excavations since micropiles can be designed to provide substantial axial load-carrying ability and modest lateral load bearing.

The North-Western Himalayas are home to several major landslides in the past. Landslides are natural hazards caused by natural or anthropogenic or both reasons. Usually, antecedent rainfall or earthquake motions cause catastrophic landslides in the form of debris slides or rock falls. Due to landslides, each year, many lives are lost, road connectivity is affected, and economy suffers. Hence, it is of utmost importance to develop not only landslide hazards maps through slope stability assessment, but also to prepare appropriate design of control measures. There are various control measures to mitigate the risk and effect of landslides, such as surface dressing and

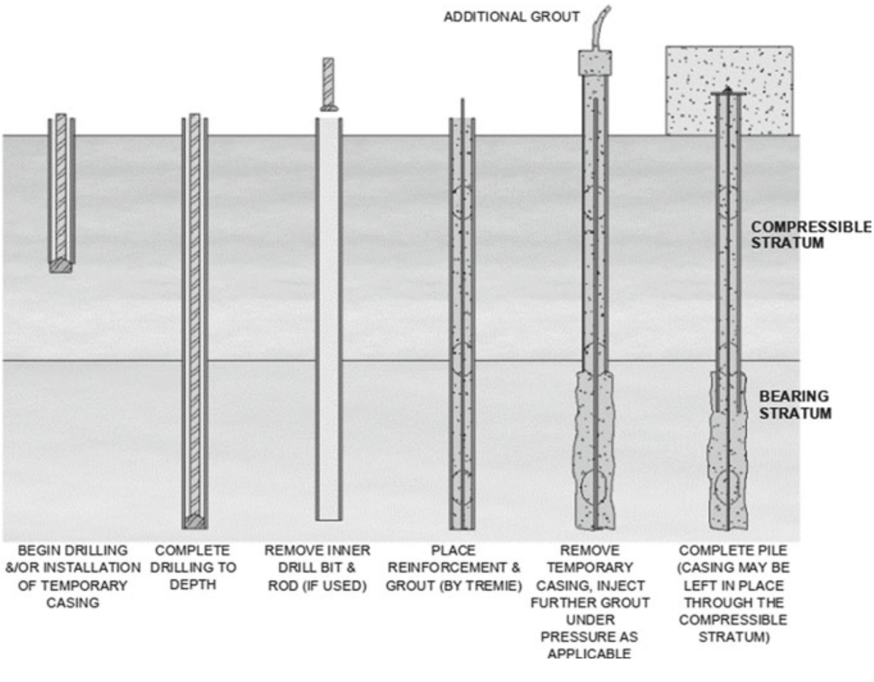

Fig. 1 Construction sequence of micropiles, after Sabatini et al. [1]

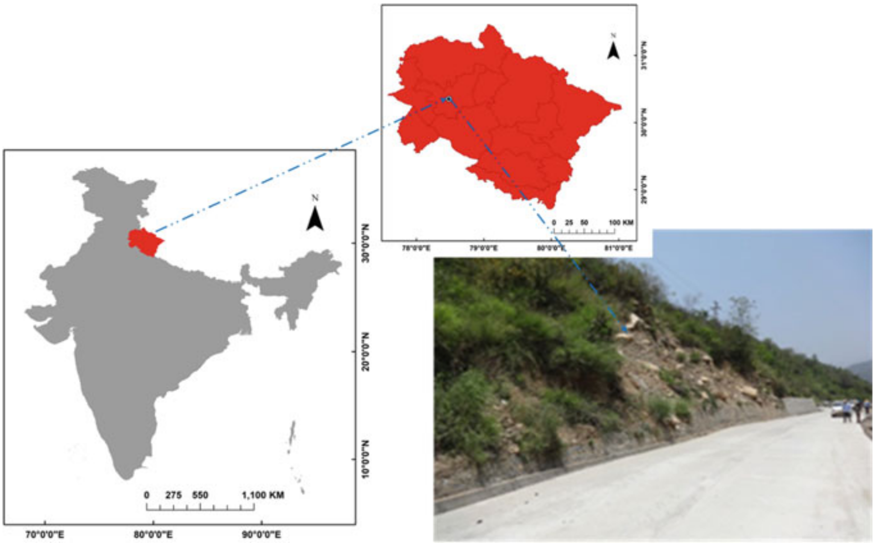

Fig. 2 Study location of the debris slope in the present work

reprofiling, geo-synthetic or soil nailing, rock-bolting, pile reinforcement, retaining walls, and bio-engineering measures or a combination of some of these methods.

In the present study, an active landslide in Tehri Garhwal district of Uttarakhand state of India (Fig. 2) has been chosen for demonstration of micropile reinforcement technique. After characterization of the slope material, factor of safety of the untreated slope under different degree of saturation have been evaluated by utilizing different limit equilibrium methods for static and pseudo-static conditions. Since the failure surfaces for all the simulated scenarios have been obtained at deeper depths, it was fathomed that deep-seated slip movements need to be arrested partially or fully for which slope reinforcement with micropiles will be a good choice. A parametric analysis was conducted to assess stability of the slope with single rows of micropiles with different diameter, spacing, and aspect ratios. The results show that the slope stability improves satisfactorily for certain cases.

2 Geotechnical and Geological Investigations

The study area is located at 30°16′00.00″N, 78°29′19.86″E coordinates, in the downstream of the Bhagirathi River and about 12.55 km away from the Tehri dam. Also, near the sliding zone, an old pump-house building is placed. Hence, safety of this building as well as the road crossing below is important. The study area has a highly undulating terrain. It has been observed from the exposed rocks in the study area that these rocks belong to the inner Lesser Himalayas, as well as to the outer Lesser

Himalayas. Details about these rock formation and sub-group classifications can be found in [2]. The underlain bedrock of the studied slope has mostly phyllites, a metamorphic rock, having experienced weathering in the range of moderate to high and possess well-developed foliation planes and discontinuities, thus making the slope extremely susceptible to landslide. The North Almora Thrust (NAT) is situated in the south of the study area. Also, a slip fault is existing parallel to the NAT in the same valley which coincides lastly [3]. Hence, it can be noticed that the study slope has high probability of experiencing a significant earthquake due to presence of this thrust line. The study area catchment experiences heavy rainfall throughout the year (1016 to 2630 mm/year) [4]. As part of the geotechnical investigations, sample debris and rock materials were collected from the site and laboratory tests were performed to characterize the slope materials. The shear strength parameters of the debris were determined through large size direct shear tests. Also, the equivalent shear strength properties of the rock mass have been determined by fitting the GSI value of the rock mass as obtained from field investigations into Rocdata, a software from Rocscience, which provides the equivalent Mohr–Coulomb parameters of the rock mass. These parameters hold high significance since they are key inputs to determine the stability a slope.

3 Limit Equilibrium Analysis

For slope stability analysis, limit equilibrium methods are widely utilized by the geotechnical research community because of their simplicity in obtaining the input parameters experimentally or through field observations. There are many limit equilibrium methods available; however, for the present study, to evaluate the global factor of safety of the slope under the influence of static i.e., gravity loading and pseudo-static loading conditions, the Bishop's method [5], Morgenstern and Price method [6], and Spencer's method [7] were used. For this, Slide2 program from Rocscience was used which incorporates various well-established and popular two-dimensional stability assessment. In the pseudo-static method, the basic principle is to apply a seismic load in terms of an equivalent static inertial force applied on the slope mass. The value of this equivalent static inertia is nothing but the product of a chosen seismic coefficient (k) according to the earthquake standard IS 1893:2016 and the weight of the potential sliding mass. The study slope is located in seismic zone IV. Also, the area receives ample amount of rainfall, especially during the monsoons. Hence, the slope is modeled and analyzed for different pore water pressure coefficient values with and without the inclusion of pseudo-static acceleration coefficient values. The soil is modeled by elastic perfectly plastic model with the Mohr–Coulomb failure criterion. However, an elastic pile was assumed for the analysis which means that the yielding of the pile itself cannot be identified, and it is a limitation of the present results.

The slope model section prepared is shown in Fig. 3. The slope material properties are also listed in the table provided with Fig. 3. The micropile location was finalized

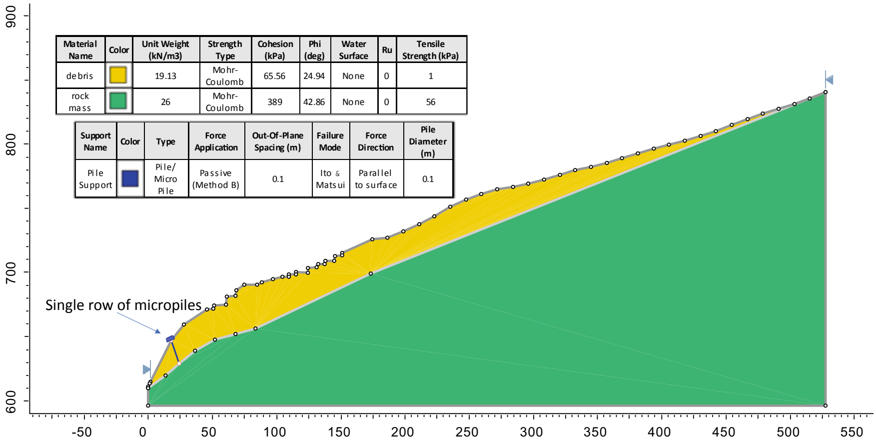

Fig. 3 Slope geometry showing proposed installation location of micropiles

after observing the most probable slip surface having the lowest global minimum safety factor for the untreated slope (Fig. 4). Once the location of micropiles was fixed, the next job was to carry out a parametric study on the design aspect of the micropiles, i.e., their diameters (d), in-plane spacings (s = 1-, 1.5- and 3-times diameter) and the aspect ratios (L/d). For this, two different diameters (d), e.g., 100 mm and 300 mm were considered with micropile lengths (L) of 19.43 m (the length from slope face to the interface between the debris and the underlying rock mass) and 25 m (assuming an almost 6 m socketed length inside the relatively stable rock mass).

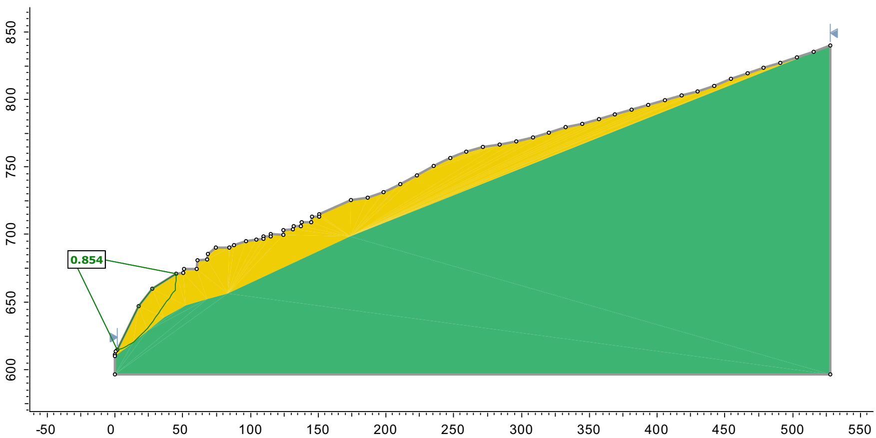

Fig. 4 Slope geometry showing the most probable slip surface having the lowest global minimum safety factor for the untreated slope

4 Results and Discussions

A total of 48 scenarios have been simulated for slope stability evaluation of the selected slope, first with no micropile reinforcements and then with micropile installations, with various diameters, lengths, and aspect ratios. The scenarios depict cases of slope stability from a dry slope condition with no effect of pore water pressure (as may be generated during a rainfall event) or any seismic effects, to a wet slope condition having pore water pressure coefficient (R_u, defined as the ratio of the generated pore pressure to the overburden pressure) value assumed as 0.1 (since as per Sassa, 1988 [8], around 90% saturation in debris material generally occurs at Skempton's pore water pressure parameter B = 0.1; in absence of any site data, 90% saturation is considered as the worst possible scenario for the present case study) and with pseudo-static seismic acceleration coefficient values of 0.12 (in horizontal direction) and 0.08 (in vertical direction). The global minimum safety factors (FoS) obtained from different limit equilibrium methods are listed in Table 1 for the untreated slope. As it can be seen that the slope is having FoS values less than the critical FoS of 1.0, hence, the slope is unstable inherently and need support measures to improve its stability. For this, micropile reinforcements have been proposed due to the obvious advantages associated with them. Also, the slip surface passes at greater depth, and hence, any surficial support installed on the slope face might not be that much useful, and may either add more overburden pressure on the slope, thus making the slope more unstable or, the installed support measure may get slide down along with the unstable slope mass beneath it due to the presence of a deeper slip surface. The FoS values as obtained for the different scenarios with micropile reinforced slope are provided in Table 2.

From the obtained results, it can be inferred that the stability of the slope increases sufficiently from below 1.0 value to 1.488 for scenario 1 which is dry slope condition with no pore water pressure and seismic effects. As the in-plane spacing increases, the safety factor reduces and reaches below 1.0 level for a few instances, which basically means that the support design schemes are inefficient in those cases and hence are to be discarded. Another vital observation was that since the slip surface is cutting the micropiles at a depth, hence socketing the piles inside the bedrock does not fetch

Table 1 Global minimum safety factors (FoS) as obtained from different limit equilibrium methods for the untreated slope

Scenario	Loading condition	Pore water pressure (R_u)	FoS from Bishop's LEM [5]	FoS from Morgenstern and Price's (MP) LEM [6]	FoS from Spencer's LEM [7]
1	Static	0	0.854	0.855	0.862
2	Pseudo-static	0	0.721	0.714	0.726
3	Static	0.1	0.752	0.747	0.749
4	Pseudo-static	0.1	0.635	0.624	0.625

Table 2 Global minimum safety factors (FoS) as obtained for the different scenarios with micropile reinforced slope

Sl	Loading	R_u	Diameter (m)	In-plane spacing (m)	Length (m)	FoS from Bishop's LEM [5]	FoS from MP's LEM [6]	FoS from Spencer's LEM [7]
1	Static (S)	0	0.1	0.10	19.43	1.464	1.461	1.488
2	S	0	0.1	0.10	25.00	1.464	1.461	1.488
3	S	0	0.1	0.15	19.43	1.466	1.463	1.486
4	S	0	0.1	0.15	25.00	1.461	1.459	1.488
5	S	0	0.1	0.30	19.43	1.293	1.230	1.249
6	S	0	0.1	0.30	25.00	1.298	1.235	1.243
7	S	0.1	0.1	0.10	19.43	1.345	1.346	1.367
8	S	0.1	0.1	0.10	25.00	1.345	1.346	1.367
9	S	0.1	0.1	0.15	19.43	1.344	1.342	1.367
10	S	0.1	0.1	0.15	25.00	1.342	1.344	1.369
11	S	0.1	0.1	0.30	19.43	1.182	1.113	1.121
12	S	0.1	0.1	0.30	25.00	1.182	1.110	1.117
13	Pseudo-Static (PS)	0	0.1	0.10	19.43	1.174	1.154	1.175
14	PS	0	0.1	0.10	25.00	1.173	1.153	1.174
15	PS	0	0.1	0.15	19.43	1.173	1.157	1.173
16	PS	0	0.1	0.15	25.00	1.177	1.158	1.173
17	PS	0	0.1	0.30	19.43	1.093	1.015	1.025
18	PS	0	0.1	0.30	25.00	1.086	1.022	1.028
19	PS	0.1	0.1	0.10	19.43	1.076	1.056	1.074
20	PS	0.1	0.1	0.10	25.00	1.074	1.056	1.075
21	PS	0.1	0.1	0.15	19.43	1.076	1.056	1.075
22	PS	0.1	0.1	0.15	25.00	1.076	1.058	1.076
23	PS	0.1	0.1	0.30	19.43	0.987	0.930	0.949
24	PS	0.1	0.1	0.30	25.00	0.991	0.918	0.948
25	S	0	0.3	0.30	19.43	1.464	1.461	1.488
26	S	0	0.3	0.30	25.00	1.464	1.461	1.488
27	S	0	0.3	0.45	19.43	1.464	1.459	1.490
28	S	0	0.3	0.45	25.00	1.465	1.460	1.488
29	S	0	0.3	0.90	19.43	1.290	1.228	1.242
30	S	0	0.3	0.90	25.00	1.301	1.232	1.242
31	S	0.1	0.3	0.30	19.43	1.345	1.346	1.367
32	S	0.1	0.3	0.30	25.00	1.345	1.346	1.367

(continued)

Table 2 (continued)

Sl	Loading	R_u	Diameter (m)	In-plane spacing (m)	Length (m)	FoS from Bishop's LEM [5]	FoS from MP's LEM [6]	FoS from Spencer's LEM [7]
33	S	0.1	0.3	0.45	19.43	1.346	1.342	1.368
34	S	0.1	0.3	0.45	25.00	1.344	1.343	1.367
35	S	0.1	0.3	0.90	19.43	1.180	1.108	1.117
36	S	0.1	0.3	0.90	25.00	1.175	1.114	1.122
37	PS	0	0.3	0.30	19.43	1.174	1.154	1.175
38	PS	0	0.3	0.30	25.00	1.173	1.153	1.174
39	PS	0	0.3	0.45	19.43	1.171	1.151	1.172
40	PS	0	0.3	0.45	25.00	1.168	1.152	1.173
41	PS	0	0.3	0.90	19.43	1.083	1.011	1.024
42	PS	0	0.3	0.90	25.00	1.094	1.018	1.022
43	PS	0.1	0.3	0.30	19.43	1.076	1.056	1.074
44	PS	0.1	0.3	0.30	25.00	1.074	1.056	1.075
45	PS	0.1	0.3	0.45	19.43	1.077	1.058	1.075
46	PS	0.1	0.3	0.45	25.00	1.079	1.062	1.078
47	PS	0.1	0.3	0.90	19.43	0.993	0.921	0.928
48	PS	0.1	0.3	0.90	25.00	0.981	0.938	0.946

much advantage in terms of the safety factor. Hence, cost saving can be achieved if the micropile length is restricted to 19.43 m. A design chart (Fig. 5) is prepared for the safety factor variation with respect to the in-plane spacing to diameter ratio. From the analysis of scenario 1 (Fig. 6), it can be observed that the shear strength has been increased and is larger than the shear stress generated along the most probable slip surface along which the global minimum safety factor is obtained. Figure 7 indicates that the micropile has significantly increased the shear strength.

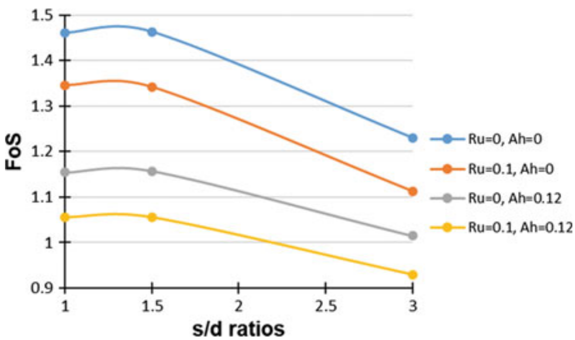

Fig. 5 Variation of the factor of safety values with respect to different spacing to micropile diameter ratios for 0.1 m diameter micropile

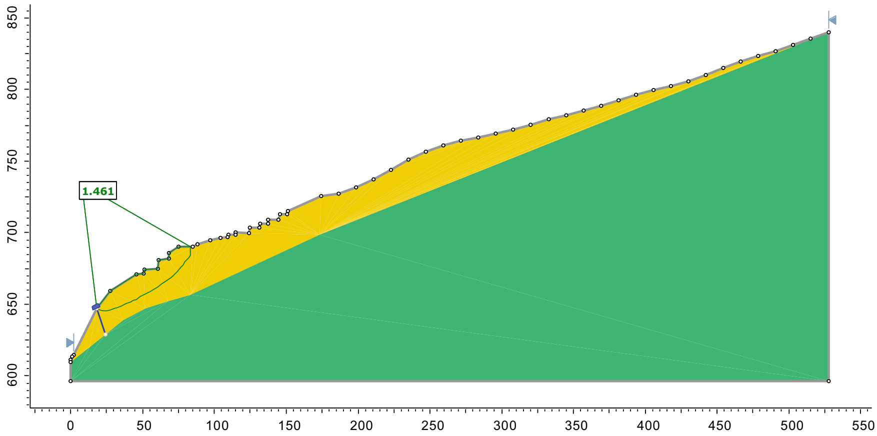

Fig. 6 Slope stability condition for scenario 1 with micropiles installed

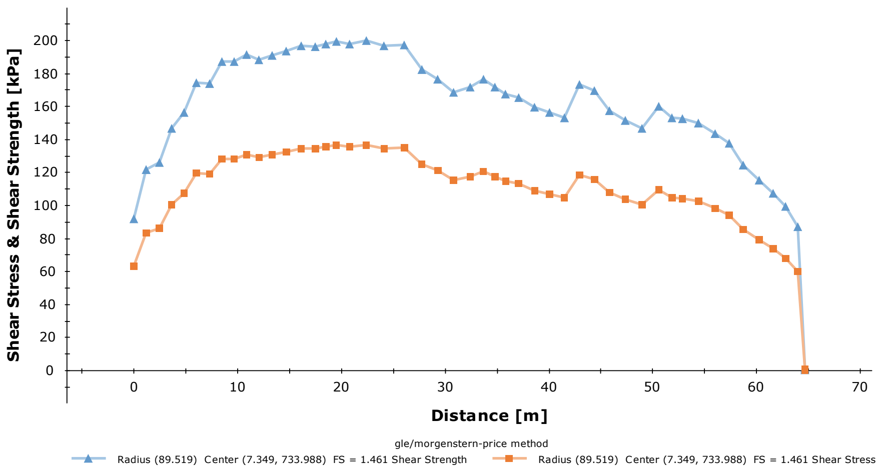

Fig. 7 Variation of the shear strength and shear stresses along the most probable slip surface (for FoS = 1.461) for scenario 1 of the slope with micropiles installed

5 Conclusions

The present study provides an overview of the stability assessment methods using the limit equilibrium methods, such as the Bishop's [5], Morgenstern and Price's [6], and Spencer's [7] methods. These methods are very popular and incorporate various assumptions and simplifications. Moreover, the deformation behavior of the slope strata cannot be obtained from the LEM, for which a finite element method can be adopted to perform the coupled analysis. The presented methodology can be adopted for a rapid stability analysis of the slopes which need micropile reinforcements to improve their stability. As it was found from the study that the micropiles even if installed in just a single row, can improve the overall slope stability significantly if the micropile installation location is chosen wisely and a parametric analysis such as that performed here can be very helpful in reducing cost of construction since the pile diameter, in-plane spacings and aspect ratios are optimized and chosen for the desired level of safety factor.

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Strengthening Measures

Optimal Design of True Negative Stiffness Damper as a Supplemental Damping Device for Base-Isolated Structure

Naqeeb Ul Islam and R. S. Jangid

Abstract An analytical study on a true negative stiffness damper (NSD) in the form of negative stiffness amplifying damper (NSAD) is presented. NSD proposed in this study for controlled base isolator displacement uses damping magnification effect that guarantees the efficient reduction in base displacement and inter-storey drift whilst utilising minimum damping coefficient of NSAD dashpot. Dynamic equations of motion are represented in the state-space form. A simple optimisation design for NSAD is proposed using complex eigenvalue analysis of the system matrix. Optimal parameters for NSAD are developed considering the stability of the system and effective fundamental mode damping. Optimal NSAD is supplemented to MDOF base-isolated shear structure as NSD. A suite of six ground motions consisting of three near-fault (NF) and three far-field (FF) motions are used in this study. For comparison purpose, viscous damper (VD) and visco-elastic damper (VED) are used as conventional supplemental dampers to the base-isolated shear structure. Base shear, top storey acceleration and inter-storey drift are three objective variables that are monitored for the effectiveness of supplemental dampers. Results of the time history analysis show that NSAD works as an efficient supplemental damping system for both NF and FF ground motions in contrast to conventional dampers.

Keywords Negative stiffness dampers · Passive structural control · Base isolation · Supplemental damping · Near fault motions

1 Introduction

Altering the dynamic response of a structure due to vibration input has been the most researched field in control dynamics over the past few years. Base isolation is considered a strong strategy in reducing the dynamic response of structures subjected

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to strong ground motions or far-field (FF) motions. Although base-isolated structures have proven to be very protective against earthquakes, large isolator displacement is a big concern, especially under near-fault (NF) excitations. Forward site directivity produces near-fault motion (NF) having large velocity pulses and can bring seismic isolation devices to a critical working condition [1]. The near-fault zone is typically assumed restricted to within a distance of about 20 km from the ruptured fault [2]. Most of the service lines pass through the isolator slabs and can't withstand such large displacements. Standard practice to reduce base isolator displacement is to supplement the base isolator with conventional dampers. However, there is a problem associated with conventional dampers; when there is a higher demand for damping, it can result in higher mode participation. A high value of damping requirement for near-fault motions (to reduce isolator displacement) becomes exceptionally high for the case of moderate earthquakes or FF motions [1, 3]. Thus, the primary objective of base isolation (namely, reducing the superstructure drift and acceleration) is defeated. Hence, base-isolated structures subjected to near-fault motions benefit from high supplemental damping devices compared to those subjected to far-fault motions [4].

Over the past decade, negative stiffness dampers (NSD) have created a stir in structural control engineering. NSD is passive devices that utilise compressed spring (working on the principle of force assisting motion) and damper configuration. A combination of true negative stiffness (TNS) and a passive damper (PD) proposed by Nagarajaiah et al. [5], called 'adaptive negative stiffness device (ANSD), demonstrates shifting of yielding away from the main structure to ANSD. This device has shown promising results as a control device. Analytical modelling and experimental verification of ANSD are presented in the paper by Sarlis et al. [6], and it has been proven dynamic inertia can be neglected for the most practical cases. Experimental investigation for ANSD as a controlled device has shown that acceleration and base shear are reduced by more than 30% and displacement by more than 20% [7]. Shake table testing of an isolated three-storey building supplemented with ANSD has shown a substantial reduction in base displacement, base shear, floor acceleration and inter-storey drifts [8]. For optimal placement and number of TNS devices (based on the principle of ANSD) for efficient seismic control on the MDOF shear model, analytical studies have been carried out. It has been shown NSD is superior to the conventional damper in controlling the seismic response [9].

Another version of the true negative stiffness damper is negative stiffness amplifying damper (NSAD) [10] and is a modification of the negative stiffness mechanism proposed by Sarlis et al. [6]. NSAD consists of a parallel combination of viscous damper and negative stiffness, which is in turn series connected to a positive spring. This physical realisation of NSAD is shown in Fig. 1a. It has been shown that an SDOF system supplemented with NSAD (see NSAD model Fig. 1b) achieves a magnified damping effect and preserves negative stiffness as well [10]. The application of NSAD to MDOF system and modal optimisation has been investigated by Wang et al. [11].

In this study, the optimal design of the NSAD damper is investigated in a new direction, i.e. as a supplemental damper to a five DOF base-isolated structure. In view of viscous dampers (VD) shortcomings as a supplemental damper, NSAD has

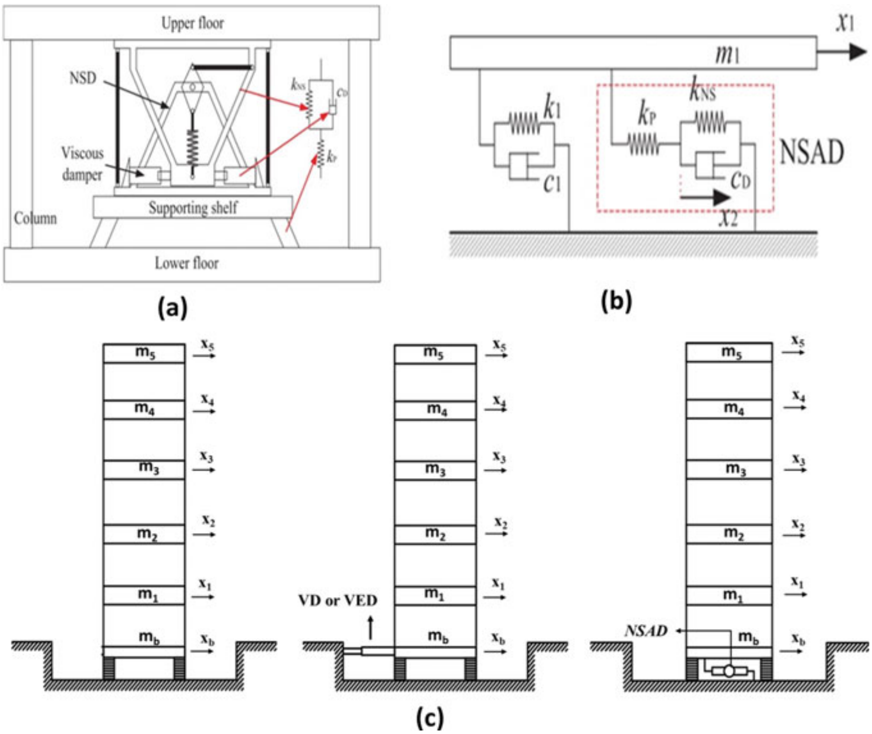

Fig. 1 **a** The physical realisation of NSAD [10] **b** An analytical model of SDOF supplemented with NSAD [10] **c** Schematic representation of four case studies

been proposed as a better supplemental damper alternative to VD. Using NSD as a supplemental damper to a base-isolated structure is the first of its kind.

2 Structural Model

Base isolation has been proved from time to time as a powerful seismic isolation technique. Examples of its implementation are many. Seismic isolation using rubber bearing is the main point of this study. From now onwards, base isolation will synonymously mean rubber base isolation. An analysis of displacement control of base isolators by supplemental damping devices is presented. The damping devices used in this study are viscous dampers (VDs), visco-elastic dampers (VEDs) and negative stiffness amplifying dampers (NSADs). Previously, it has been shown that supplemental dampers effectively reduce the base displacement of base-isolated structures [1]. However, using NSAD as a supplemental damper to a base-isolated structure is the first of its kind. In this study, a contrast between the effectiveness of VD, VED and NSAD as an additional damper for base displacement control (of base-isolated structure) has been shown.

A five-storey shear building has been isolated with a linear isolator to study the performance of NSAD as a supplemental damper. For modelling and analysing the structure, some simplifying assumptions are made: (i) structure is linear, and stories are rigid (ii) no torsional effect on stories (iii) soil-structure interaction is neglected. In total, five case studies have been made: (1) fixed base structure (FB) (2) base-isolated structure with no supplemented damping (BI) (3) base-isolated with NSAD (BINSAD) (4) base-isolated with viscous damper (BIVD) (5) base-isolated with visco-elastic damper (BIVED).

2.1 Fixed Base Structure (FB)

In this study, mass and stiffness are assumed to be uniformly distributed throughout the building, i.e. all lumped masses are equal, and each storey stiffness is the same. The mass associated with each DOF is 5000 kg, and the stiffness of each storey is 1.5228×10^7 N/m. The fundamental time period (T_n) for the FB model is chosen as 0.4 s. The damping ratio for the first two modes is assumed as 0.02, and the rest modes are calculated using Rayleigh damping. Figure 1c shows the schematic representation of case studies.

2.2 Base Isolated Structure (BI)

Properties of the base isolator (linear) are damping ratio $\zeta_b = 0.1$, isolating time period $T_b = 1.75$ secs and mass $m_b =$ 5000kgs. Governing equation of motion for the base-isolated structure subjected to ground motion [12]:

$$\begin{bmatrix} m_t & \{r^T\}[m] \\ [m]\{r\} & [m] \end{bmatrix} \begin{Bmatrix} \ddot{x}_b \\ \ddot{x} \end{Bmatrix} + \begin{bmatrix} c_b & 0 \\ 0 & [c] \end{bmatrix} \begin{Bmatrix} \dot{x}_b \\ \dot{x} \end{Bmatrix} + \begin{bmatrix} k_b & 0 \\ 0 & [k] \end{bmatrix} \begin{Bmatrix} x_b \\ x \end{Bmatrix} = -\begin{Bmatrix} m_t \\ [m]\{r\} \end{Bmatrix} \ddot{x}_g \tag{1}$$

Here, m_t = total storey mass including base slab $[m]$, $[c]$ and $[k]$ are mass, damping and stiffness matrix of the 5-DOF fixed base structure, respectively; $\begin{Bmatrix} x_b \\ x \end{Bmatrix}$ is displacement vector with x_b base isolator displacement, and x is a vector of 5×1 dimension representing relative displacements with respect to base isolator of five storeys above base isolator; $\{r\}$ is the unit vector of 5×1 order.

2.3 Base Isolated with NSD (BINSAD)

The schematic representation of the NSAD has been shown in Fig. 2. NSAD can be practically introduced between the base slab foundation, just like isolator bearings. NSAD is defined by parameters named as alpha (α), beta (β) and gamma (γ). These parameters are defined as follows: α is the ratio of negative stiffness of NSAD (k_{ns}) and positive stiffness of NSAD (k_p); β is the ratio of positive stiffness of NSAD (k_p) and base isolator stiffness (k_b); γ is the ratio of NSAD damping (c_d) and base isolator damping (c_b).

Force equation for NSAD can be written as:

$$F_d = k_p(x_b - p) = c_d \dot{p} + k_{\text{ns}} p \tag{2}$$

Here, x_b is the total displacement of the base isolator, and p is the deformation of the NSAD dashpot, as shown in Fig. 2. In a modified form, this equation can be written as:

$$F_d + \frac{c_d}{k_p + k_{\text{ns}}} \dot{F}_d = \frac{c_d \times k_p}{k_p + k_{\text{ns}}} \dot{x}_b + \frac{k_p \times k_{\text{ns}}}{k_p + k_{\text{ns}}} x_b \tag{3}$$

$$or, \quad F_d + \tau \dot{F}_d = \pi \dot{x}_b + \sigma x_b \tag{4}$$

Matrix equation of motion of base-isolated structure with NSAD can then be written as:

$$\begin{bmatrix} m_t & \{r^T\}[m] \\ [m]\{r\} & [m] \end{bmatrix} \begin{Bmatrix} \ddot{x}_b \\ \ddot{x} \end{Bmatrix} + \begin{bmatrix} c_b & 0 \\ 0 & [c] \end{bmatrix} \begin{Bmatrix} \dot{x}_b \\ \dot{x} \end{Bmatrix} + \begin{bmatrix} k_b & 0 \\ 0 & [k] \end{bmatrix} \begin{Bmatrix} x_b \\ x \end{Bmatrix} + \{\lambda\} * F_d = -\begin{Bmatrix} m_t \\ [m]\{r\} \end{Bmatrix} \ddot{x}_g \tag{5}$$

or,

$$[M_{\text{NS}}][\ddot{X}] + [C_{\text{NS}}][\dot{X}] + [K_{\text{NS}}][X] + \{\lambda\} F_d = -[M_{\text{NS}}]\{rr\}\ddot{x}_g \tag{6}$$

Here, vector λ of 6 × 1 dimension is defined as:

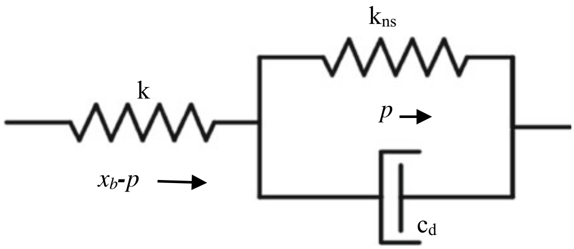

Fig. 2 Schematic representation of NSAD

$$\lambda = \begin{Bmatrix} 1 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \end{Bmatrix} \tag{7}$$

Here, symbols have their usual meaning, as defined in the previous section. Force equation for NSAD is modified to a vector equation by using vector λ, X and $\dot{X}$. This equation is presented below:

$$F_d + \tau \dot{F}_d = \pi \lambda^T \dot{X} + \sigma \lambda^T X \tag{8}$$

Now, a state-space model is written for the base-isolated structure with NSAD as a supplemental damper. Three states are defined velocity, displacement and damping force. Thus, state variable z is defined as:

$$z = \begin{Bmatrix} \dot{X} \\ X \\ F_d \end{Bmatrix} = \begin{Bmatrix} \dot{x}_b \\ \dot{x} \\ x_b \\ x \\ F_d \end{Bmatrix} \tag{9}$$

The state-space representation matrices (A, B, C and D) are defined below. A is the state matrix, B is the input matrix, C is the output matrix, and D is the feedthrough vector.

$$A = \begin{bmatrix} -M_d^{-1}C_d & -M_d^{-1}K_d & -M_d^{-1}\lambda \\ 0_{6\times6} & I_{6\times6} & 0_{6\times1} \\ \left(\tau^{-1}\pi\lambda^T\right)_{1\times6} & \left(\tau^{-1}\sigma\lambda^T\right)_{1\times6} & -\tau^{-1}_{1\times1} \end{bmatrix}; B = \begin{bmatrix} rr_{6\times1} \\ 0_{6\times1} \\ 0_{1\times1} \end{bmatrix};$$
$$C = \begin{bmatrix} 0_{6\times6} & I_{6\times6} & 0_{6\times1} \\ -M_d^{-1}C_d & -M_d^{-1}K_d & -M_d^{-1}\lambda \\ 0_{1\times6} & 0_{1\times6} & I_{1\times1} \end{bmatrix}; D = \begin{bmatrix} 0_{6\times1} \\ rr_{6\times1} \\ 0_{1\times1} \end{bmatrix} \tag{10}$$

If C and D are used as defined above, then the output will be a 13×13 vector defined as:

$$y = \begin{Bmatrix} X \\ \ddot{X} \\ F_d \end{Bmatrix} = \begin{Bmatrix} x_b \\ x \\ \ddot{x}_b \\ \ddot{x} \\ F_d \end{Bmatrix} \tag{11}$$

Optimisation whilst introducing negative stiffness into the system, the stability of the system is the prime concern. NSAD parameters α, β and γ, are optimised to get the system's best possible response. Optimal values of NSAD parameters are calculated by taking into account the stability of the system. For static loading, NSAD becomes a series combination of positive stiffness (k_p) and negative stiffness (k_{ns}), and total stiffness of the system (K_{TE}) becomes:

$$K_{TE} = \frac{k_p k_{ns}}{k_p + k_{ns}} \quad (12)$$

Total stiffness K_{TE} can be written in the following form by using NSAD parameters:

$$K_{TE} = \frac{\alpha\beta}{1+\beta} k_b \quad (13)$$

For the stability of the system $K_{TE} + k_b > 0$. For this condition to be true, constrain on α for a chosen value of β can be written as:

$$\alpha > \frac{-1}{1+\beta} \quad (14)$$

The analytical analysis also shows that if α is less than the prescribed value, the system becomes unstable (diverging). To find the optimum value of γ for the other two NSAD parameters' chosen value, eigenvalue analysis of state matrix "A" is run for varied values of γ. Plots between modal damping ratios and γ are given in Fig. 3 for four values of α. Values of α are chosen for $\beta = 2$. From the plots following observations can be made: damping ratios for higher modes are very small and nearly constant for changing values of γ, which goes with basic tenants of base isolation. As the values of γ are increased, the first mode damping ratio increases to a maximum and then decreases. As the values of α are increased (magnitude), the peak value of first mode damping also increases. As the value of α increase (magnitude), peak values of first mode damping move towards the left, i.e. a lower value of γ attains peak. There is an upper limit to the maximum absolute value of α, so this value can't be increased beyond that limit (0.333 for $\beta = 2$). If the value of α is in the vicinity of its limit, the fundamental damping ratio peak increases to an overdamped one, i.e. greater than 1, which is desirable. However, it will result in instability of the system and hence, limit to the value of α is specified.

The magnitude of α in the study has been chosen 0.95/(1 + β), and this is the optimum value of α. Thus, for a given value of β, optimum value of α is fixed. This value is near to maximum limit on α so that the lower possible value of γ is required for a higher fundamental damping ratio. Thus,

$$\alpha_{optimum} = \frac{-0.95}{(1+\beta)} \quad (15)$$

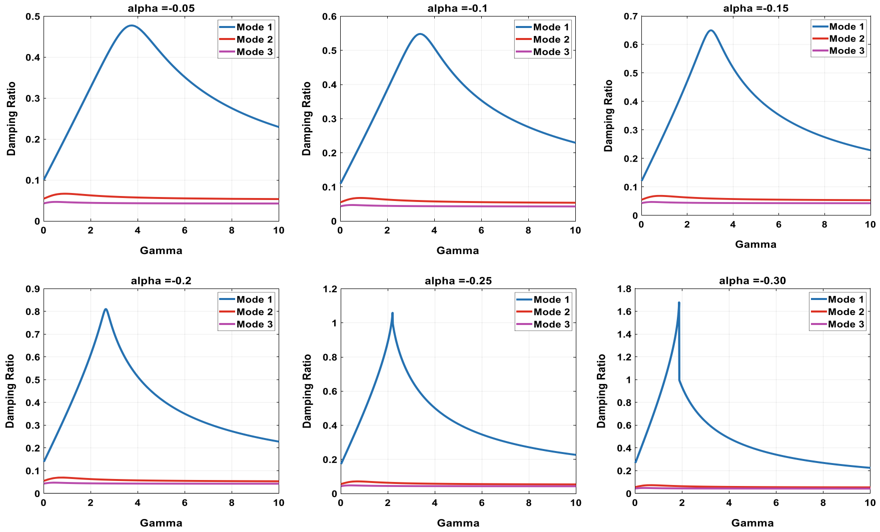

Fig. 3 Plots between damping ratio and gamma for various alpha

A three-dimensional optimisation plot between the first mode damping ratio, β and γ is plotted in Fig. 4. Each curve is plotted for $\alpha = \alpha_{\text{optimum}}$. These plots are utilised to choose the value of γ corresponding to the maximum first mode damping ratio. From the optimisation plots, for $\beta = 2$, the value of $\gamma = 1.85$ is selected for analysis.

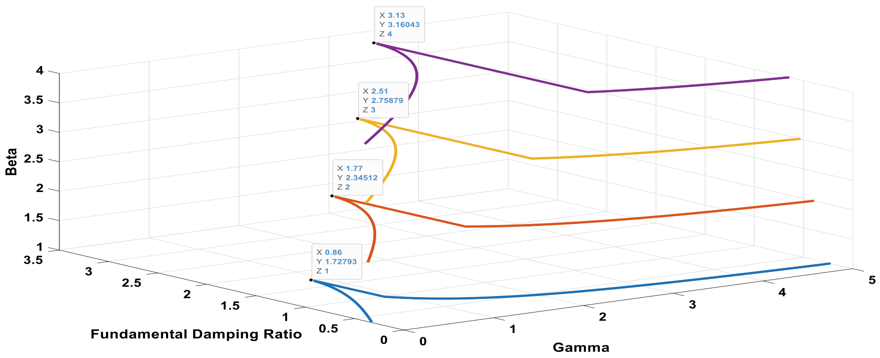

Fig. 4 Optimisation plots

2.4 Base Isolated with VD (BIVD)

A VD is used for comparison with NSAD. The damping ratio of VD (ζ_{VD}) used for the study is 0.185, which is the same as the NSAD damping ratio. Choosing the same value of damping will ensure proper comparative study.

2.5 Base Isolated with VED (BIVED)

The damping ratio of VED (ζ_{VED}) and positive stiffness of VED (K_{pVED}) are equal to the damping ratio of NSAD (ζ_{NSAD}) and magnitude of negative stiffness of NSAD (k_{ns}), respectively.

3 Numerical Study

In this study, six real earthquake records are selected to evaluate the effectiveness of NSAD as a supplemental damper to the base-isolated structures. Three far-field (FF) and three near-fault (NF) ground motions are described in Table 1. Base shear, top storey acceleration and inter-storey drift are three objective variables monitored for the effectiveness of supplemental dampers. Although conventional dampers reduce the base displacement to a certain level but at the cost of higher base shear, top storey acceleration and inter-storey. This section shows NSDs are more effective in comparison with conventional VD (Figs. 5, 6 and 7).

Base displacements for both FF and NF earthquakes are shown in Fig. 5. Note from the plot that NF motion base displacements are substantial for the BI case. However, after providing supplemental damping devices, there is a considerable decrease in base displacement. For instance, in Northridge (Sylmar Olive), ground motion residual displacements of 236 mm, 300 mm and 290 mm are reported for BINSAD, BIVD and BIVED, respectively. Whilst using supplemental dampers to control the base displacement, the acceleration of stories may increase substantially,

Table 1 A suite of ground motions in this study

S.No	Earthquake	Station	Magnitude	Rjb (km)	Type
1	Tabas Iran (1978)	Ferdows	7.35	89.76	FF
2	Loma Prieta (1989)	Richmond City Hall	6.93	87.78	FF
3	Imperial Valley-06 (1979)	Coachella Canal #4	6.53	49.1	FF
4	Northridge (1994)	Sylmar Olive	6.69	1.74	NF
5	Imperial Valley-06 (1979)	El Centro Array #6	6.53	0	NF
6	Northridge (1994)	Newhall Fire Station	6.69	3.16	NF

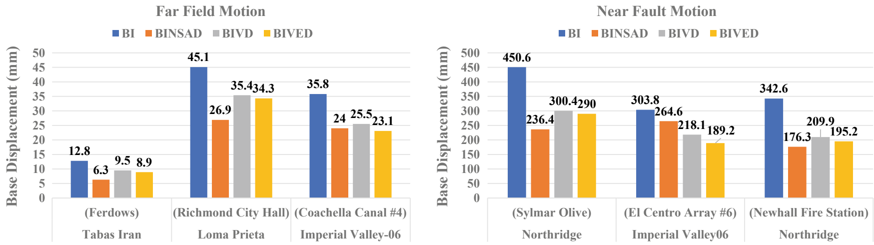

Fig. 5 Base displacement comparison plots

and this depends on the type of damper used. VED enhances the stiffness and hence increased accelerations. Variation of storey acceleration for various supplemental damping devices is shown in Fig. 7. Inter-storey shear and inter-storey drifts are related directly to each other. Variation of shear along storeys is given in Fig. 6. NSAD as a supplemental damper has proven to very effective in reducing the storey shear and base shear.

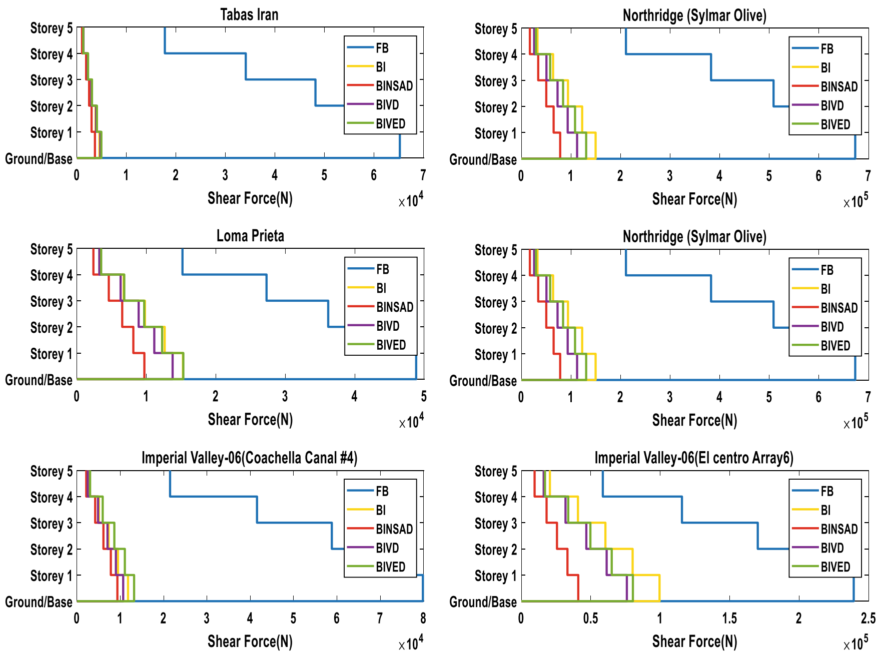

Fig. 6 Storey shear comparison **a** Far Field **b** Near Fault

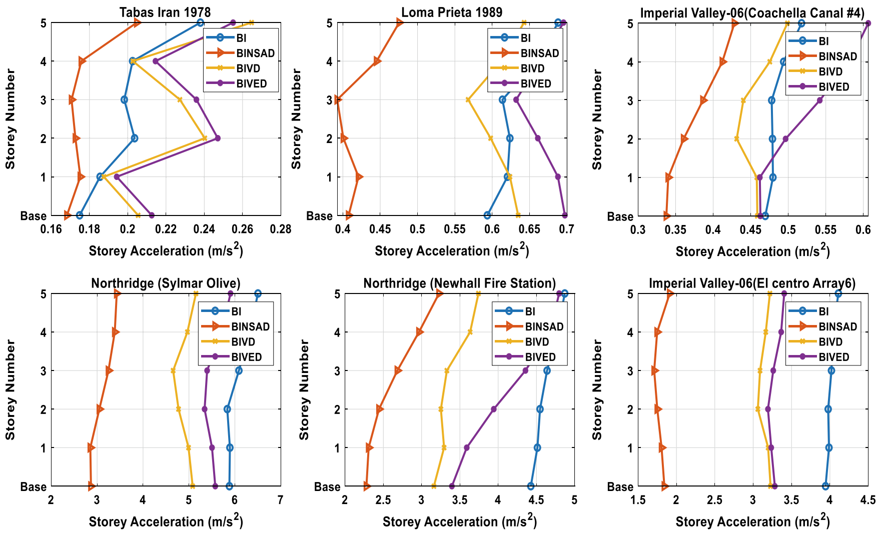

Fig. 7 Storey acceleration comparison. Top row for FF motion and bottom for NF motion

3.1 *Effectiveness of NSAD as a Supplemental Damper*

Standard practice whilst using a supplemental damper is to increase the damping ratio of the device. However, this tends to excite higher modes and result in higher storey accelerations. On the contrary, a small increase in the NSAD damping against the optimum required for FF motion decreases the base displacement and checks the storey accelerations. This has been shown in the FFT analysis results in Fig. 8.

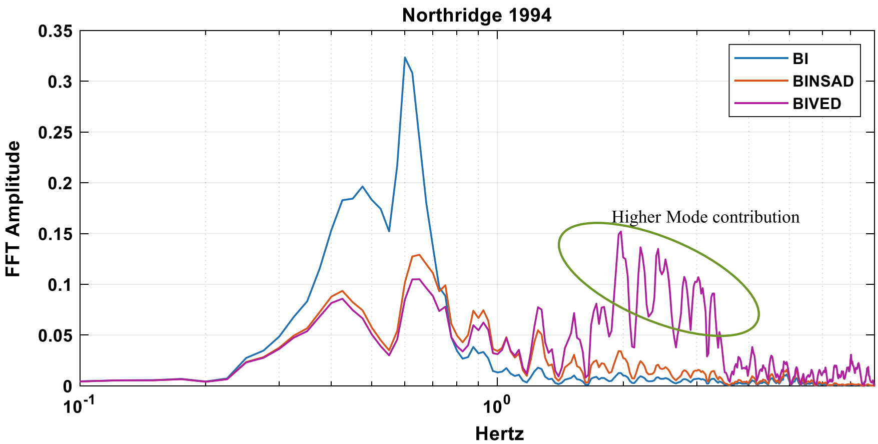

Fig. 8 FFT of top-storey acceleration for Northridge Newhall Fire Station (NF)

The viscous damping supplemented is 25 times base isolator damping, whilst NSAD damping is increased from the factor of 1.85 to 5. Thus, given a design displacement of the base isolator, one can't blindly increase the damping ratio of dampers. NSAD prevents higher mode excitation due to the dynamic magnification effect.

4 Conclusion

Base displacement reduction of a five-storey base-isolated building model has been investigated under 3-FF and 3-NF real earthquake ground motion by using NSAD as a supplemental damper. NSAD parameters are optimised based on stability and effective modal damping criteria. A contrast between optimised NSAD and conventional VD as supplemental dampers has been presented.

The following conclusions are drawn from this study:

1. Results of the dynamic analysis show effectiveness of the NSAD as a superior damper compared to VD and VED for NF and FF ground motions. In comparison with VD and VED, the reduction of base displacement is appreciable for the case of NSAD. Further on, NSAD checks storey accelerations, and values of top storey acceleration are within the vicinity of base-isolated (BI) case.
2. Optimal NSAD parameters are independent of the ground excitation. These parameters can be calculated based on stability analysis.
3. To prevent huge displacement demand corresponding to NF ground motions, introducing a higher value of damping results in higher mode excitation in the otherwise base isolation system. NSAD effectively prevents this violation of the fundamental vibration isolation principle.
4. NSAD removes the limitations of passive VD as supplemental dampers during NF event due to a higher stroke of dashpot for the same damping value.
5. Given a design displacement of the base isolator, one can't blindly increase the damping ratio of conventional passive dampers. The effectiveness of base isolation is upheld with NSAD as a supplemental damper compared to conventional passive dampers.

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Material Uncertainty Based Seismic Robustness Assessment of Steel Moment-Resisting Frames

K. M. Shaijal, Muhamed Safeer Pandikkadavath, Sujith Mangalathu, and Robin Davis

Abstract The structural robustness, that characterizes the available margin of safety against the structural collapse subjected to material uncertainty, is significant in earthquake engineering. Robustness Index is defined as the ratio of mean annual frequency of exceeding a given limit state of interest neglecting structural uncertainties to the mean annual frequency of exceeding a given limit state of interest considering all the uncertainties is often used to quantify the structural robustness. The current study quantifies the Robustness Index of a four-storey steel moment-resisting frame. Incremental Dynamic Analysis is carried out to obtain the inter-storey drift and collapse fragilities. Finally, this study estimates the robustness index in terms of Uncertainty Robustness Index and corresponding modification factors for design strength reduction factors corresponding to different hazards levels.

Keywords Robustness index · Incremental dynamic analysis · Inter-storey drift ratio · Strength reduction factor

1 Introduction to the Investigation

The safety of structures against progressive failures or collapse (disproportionate between load and resistance) under the action of seismic events can be related to their degree of robustness. Robustness is characterized as the ability of a given system to minimize the progress of localized damage, so that there will not be extensive (global) damages that may lead to the collapse [1, 2]. Alternatively, robustness can be viewed as the available margin of safety against the progressive or disproportionate collapse of the structural systems. The seismic robustness of a system depends on the extent of seismic loading, the type of the structural system, and the material properties associated with the component members [2]. Several notable investigations have been

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carried out to quantity robustness based on typology of progressive collapse [1], considering stiffness, damage, and energy [3, 4] and incorporating direct risk, indirect risk, and total risk as per decision analysis theory [5]. Recently, these concepts have been extended to assess the seismic robustness of the building structures as well [4]; which includes the concepts relying on robustness index as a measure of mean annual frequency of exceeding a given limit state of interest [2] and based on the actually vulnerable intensities (hazard types) assimilating the potential extreme event classifications [6]. The present investigation aims to assess the robustness index of a four-storey moment-resisting frame as per the mean annual frequency exceedance of a given limit state of interest concept. A simplified expression that relates the robustness with the response dispersion (of the structure) due to uncertainty in structural modeling parameters and seismic record randomness suggested by [2] has been used for the evaluation. These relations further extended to obtain the modification factor for the strength reduction factor, R which can be utilized in building design provisions to account for the material uncertainty-related effects in the structures. For finding out the robustness-related parameters, incremental dynamic analysis under a selected suite of ground motion records is carried out. The overview of robustness index, analytical modeling details, and the methodology for structural performance assessment, analysis results, and discussions are presented below.

2 Overview of Robustness Index

Taking Robustness Index as the resistance (to progressive or disproportionate collapse) of the structural system resulted from uncertainty (aleatory or epistemic); uncertainty in Robustness Index, I_r can be expressed as the ratio of the two mean annual frequency of exceedance for the given limit state of interest.

$$I_r = \frac{\lambda_R}{\lambda_{RU}} \tag{1}$$

where λ_R and λ_{RU} are the mean annual frequency of exceedance of the given limit state of interest accounting aleatory (record to record associated) and both aleatory and epistemic (record to record and material associated) randomness respectively. Numerically I_r should be greater than zero with an upper limit of 1 (it is a theoretical case of no uncertainty in the structure). The inverse of uncertainty in robustness index, $1/I_r$ is a useful indicator of structural seismic safety that gives the increase of mean annual frequency of exceedance of the given limit state of interest due to the presence of all types of accounted uncertainties. For finding the expression for the mean annual frequency of exceedance, the probability of defying a certain performance level; that is, the demand exceeding the capacity depends on the seismic hazard at the selected location can be utilized. The corresponding hazard curve, $H(s)$ can be characterized by seismic intensity measure, s conforming to the first mode spectral acceleration period, S_a (T_1). Representing demand, D and capacity, C in terms of engineering demand parameter (EDP), the fragility (conditional failure probability) $P(C < D|s)$, the mean annual frequency of exceedance (for the given limit state), λ can be expressed as follows [7].

$$\lambda = \int_0^{+\infty} P(C < D|s)\,|dH(s)| \tag{2}$$

This expression can be simplified using an approximate (with suitable assumptions) closed-form equation as described below [8]. Using power-law fit and taking k_0 and k_1 as the corresponding intercept and slope of the hazard curve respectively (in logarithmic scale); the mean curve for hazard can be approximated as follows.

$$H(s) \approx k_0 s^{-k_1} = k_0 \exp(-k_1 \ln s) \tag{3}$$

Assuming lognormal distribution for the capacity, C engineering demand parameters at the given limit state with median $\hat{\theta}_c$ and dispersion $\beta_{\theta c}$; similarly, presuming lognormal distribution for demand, D engineering demand parameter (at a given value of intensity measure, s) with fixed dispersion of $\beta_{\theta d}$, the conditional median can be written as

$$\hat{\theta}(s) \approx a s^b \tag{4}$$

where a and b are positive real number constants. Further, if the capacity is expressed in terms of intensity measure, to exceed the given limit state and assuming lognormal variation with median $\hat{s}_c$ and dispersion β_{Sc}(aleatory related), mean annual frequency considering (only) record to record variation can be estimated as

$$\lambda_R = H(\hat{s}_c)\exp\left(\frac{k_1^2}{2}\beta_{Sc}^2\right) \tag{5}$$

Taking β_{USc} as the dispersion of material randomness in the structure (epistemic related) with lognormal variation; mean annual frequency of exceedance, considering both aleatory and epistemic randomness can be expressed as

$$\lambda_{RU} = H(\hat{s}_c)\exp\left(\frac{k_1^2}{2}(\beta_{Sc}^2 + \beta_{USc}^2)\right) \tag{6}$$

Substituting Eqs. (5) and (6) in Eq. (1); the expression for Uncertainty Robustness Index, I_r can be obtained as

$$I_r = \exp\left(-\frac{k_1^2}{2}\beta_{USc}^2\right) \tag{7}$$

where $\beta_{USc} = \sqrt{\beta_{RU}^2 - \beta_R^2}$; β_R is the dispersion considering record to record (aleatory) and β_{RU} is the dispersion considering both records to record and material uncertainty (aleatory and epistemic) randomness respectively.

The above-described expressions (Eq. 7) show that the Uncertainty Robustness Index, I_r is directly related to the slope (k_1) or severity of the hazard curve and the intensity measure dispersion due to model parameter uncertainties. Developing this information further, it can demonstrate that, the inverse of Uncertainty Robustness Index, $1/I_r$ gives the hike in mean annual frequency due to the presence of structural uncertainties and thus making it a realistic quantity with effects on the structural safety [2]. Another practical use of the Uncertainty Robustness Index is that it can be employed as a direct factor to correct the collapse mean annual frequency that is obtained without uncertainties. Hence these equations can be extended further as a correction/modification factor to strength reduction factor, R (used for seismic structural design) to account for the uncertainties [9]. To account for the robustness and the influence of structural uncertainties, a modification/correction factor R_r (for strength reduction) is sufficient (approximately), and thereby desired safety can be achieved (reduction of R value to account uncertainty) [2]. The relation between the modification factor for strength reduction factor and Uncertainty Robustness Index can be written as

$$R_r = I_r^{1/k_1} \tag{8}$$

where R_r is the correction for design strength reduction factor, I_r is Uncertainty Robustness Index and k_1 power-law fit constant.

3 Analytical Modeling Details

For the analytical investigation, a four-storey building consisting of four bays along the east–west direction and three bays along the north–south direction has been selected. The design details of the study frame can be found in the references [10]. The building has constant bay width of 9.1 m along with both horizontal directions (also in all the stories); the bottom storey has a height of 4.6 m and the top storey has equal heights of 3.7 m each. The two middle bays (only) that are moment-resisting type frames along the east–west direction have opted for the numerical investigation. A centerline model of the study frame with respective beam columns and relevant geometric details is shown in Fig. 1a, b. The columns at the bottom (most) of the storey are assumed to be fixed at the base and the beams are designed to meet the AISC [11] strong column-weak beam capacity-based design approach. The beams

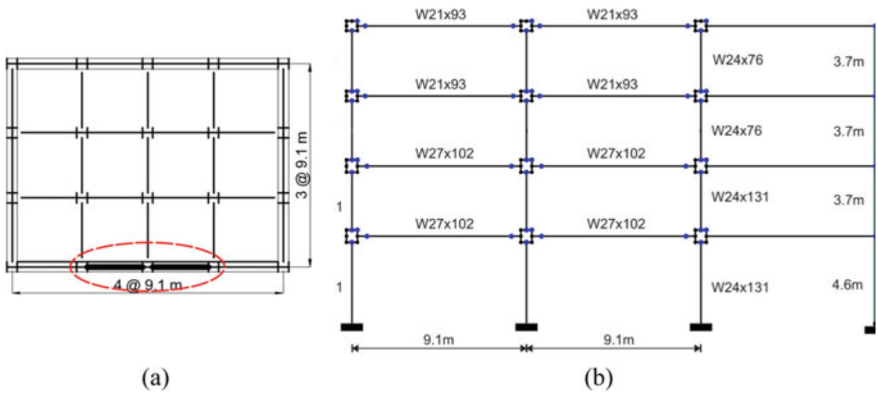


Fig. 1 **a** Plan view and, **b** structural model details of the study building frame

are incorporated with reduced beam sections near the fixity and detailed as per the FEMA recommendations to allow the plastic hinge formations [12].

The adopted 2D study frame is incorporated in the OpenSEES [13] modeling platform. The beams and columns are added as elastic elements with concentrated plasticity employing rotational springs at their respective ends. The zero-length rotational spring elements have a multi-linear hysteretic response as per the modified Ibarra-Medina-Krawinkler deterioration model (shown in Fig. 2) [14, 15]. To simulate first-order geometric nonlinearity, a P-Delta leaning column is provided at a distance of one bay width from the frame. The bottom of the leaning columns is pinned and at every other joint (with connecting axial link as well) it has moment release. This column is connected to the mainframe by an elastic axial link element

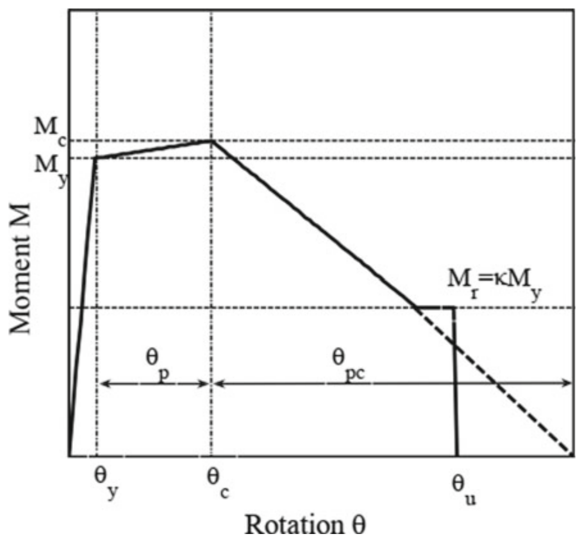


Fig. 2 Modified Ibarra-Medina-Krawinkler deterioration model for moment rotation relationship [14, 15]

without any kind of stress transfer. The shear deformation due to connection panel zones is incorporated with a tri-linear force deformation relationship characterized with concentrated spring [16]. The spring simulated plastic hinge can capture the strength and stiffness variation of the connection panel zone during its nonlinear response range. A constant Rayleigh damping of 2% is considered for the first, second, and third modes of vibrations.

4 Methodology for Structural Performance Assessment

To assess the structural performance of the chosen four-storey moment-resisting frame Incremental Dynamic Analysis, IDA approach is opted [17]. It involves a series of nonlinear dynamic response analyses for a set of ground motion records scaled at increasing (respective) intensity levels. Based on the analysis IDA curves are developed considering intensity measure, IM as 5% damped first mode spectral acceleration, $S_a(T_1, 5\%)$ of the selected ground motion records and engineering demand parameter, EDP as peak inter-storey drift ratio, IDR. For the IDA, a suite of 30 far-field ground motion records on firm soil with Peak Ground Acceleration, PGA in the range of 0.20–1.40 g (g is the earth gravity acceleration); magnitude range 6.5–7.5 (in the standard scale) and distance range from faults 10–40 km has been selected. Similarly for establishing the IDA curve and the subsequent analysis, the IDR value corresponding to 10% is taken as the collapse of the study structure.

Initially, the uncertainty due to the aleatory parameter (record to record variability related) is accounted for in the response evaluation. The IDA curve for the selected frame with a record to record variability alone is developed and corresponding response value dispersions with respect to ground motions are obtained. In the next stage to account for the epistemic randomness (related material uncertainty); Latin Hypercube Sampling Technique obtained values are incorporated. The structural model uncertainties (with suitable variations) considered for the analysis (Latin Hypercube Sampling Technique generated) are the effective elastic stiffness, K_e; pre-peak plastic rotation, θ_p; post-peak plastic rotation, θ_{pc}; effective yield moment strength, M_y; post-yield moment strength ratio M_c/M_y and critical damping, ξ (refer Fig. 2.). Corresponding to these values 30 additional moment-resisting frame realizations are defined. Corresponding to that IDA is carried out and resulting IDA curves are developed. The obtained related dispersion has been used for further analysis. Based on the two dispersion values of the Uncertainty Robustness Index, the inverse of the same has been calculated to understand the structural performance indication in terms of seismic robustness of the frame. Additionally, seismic fragility curves are developed by taking fragility as the probability of the limit state capacity, C being exceeded by demand, D for a given intensity level, s. Once capacity and demand are expressed in terms of intensity level, the representation for fragility, $P_{\text{LS}}(s)$ can be as follows.

$$P_{\text{LS}}(s) = P(C < D|s) = P(s_c < s|s) = F(s_c|s) \tag{9}$$

where s_c is the intensity measure value of the capacity that when exceeds the record violation of the limit state. F [.] is the cumulative distribution function, CDF of the argument. That is the fragility curve is the CDF of s_c evaluated at the intensity level s. Taking lognormal distribution assumption for s_c

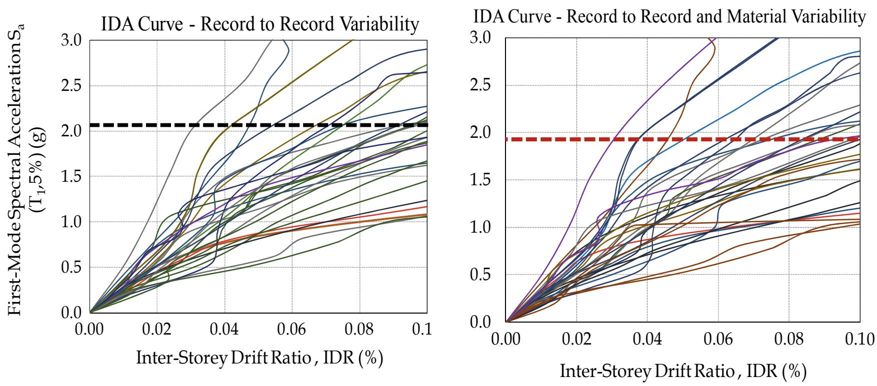
$$P_{LS}(s) = \varphi\left(\frac{\ln s - \ln s_c}{\beta_{sc}}\right) \tag{10}$$

where s_c is the median intensity measure value of the capacity and β_{sc} is the corresponding dispersion/standard deviation of the log data.

5 Analysis Results and Discussions

The influence of structural uncertainties over the considered capacity and demand are discussed below. As described earlier inter-storey drift ratio (maximum) is considered as the engineering demand parameter and the intensity measure is taken as the 5% damped first mode spectral acceleration S_a (T_1, 5%). Figure 3a, b shows the IDA curve for the cases with record to record variability (alone) and the case with record to record variability along with material uncertainty.

The median value of normalized (with respect to g) intensity measure, S_a (T_1, 5%) under the considered set of 30 ground motion generated IDA are obtained to be 2.1 and 1.9 respectively for record to record variability alone and record to record as well as material uncertainty cases. Similarly, the dispersion values corresponding to these cases are 0.38 (β_R) and 0.40 (β_{RU}) respectively. The fragility curves (as discussed in the previous sections) with respect to these two cases are plotted and



(a) (b)

Fig. 3 IDA curves **a** Record to record variability only and **b** Record to record and material variability cases

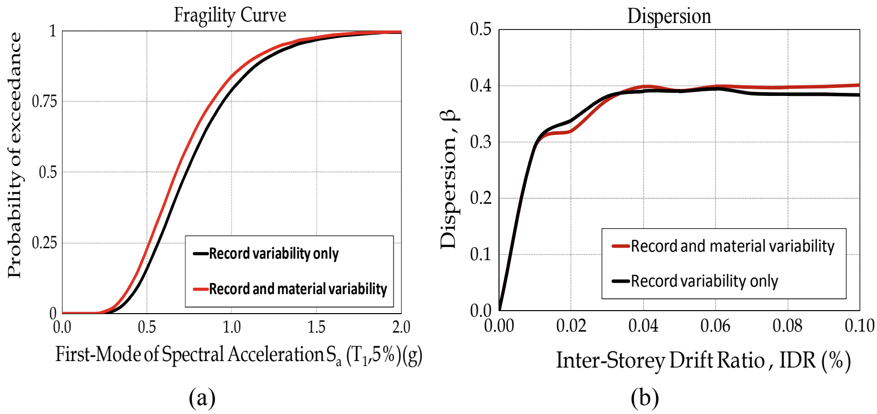


Fig. 4 **a** Fragility curves corresponding to record variability (only) and both record to record variability and material randomness and, **b** the corresponding dispersion values

shown in Fig. 4a. The collapse vulnerability corresponding to normalized intensity measure S_a $(T_1, 5\%) = 1.0$ g is obtained as 79% for without material uncertainty (record to record variation alone) and the vulnerability corresponding to the second case is found to be 84% (with record to record as well as material uncertainty).

Figure 4b shows the variation of dispersion values from the IDA curves developed corresponding to the two cases considered. From the dispersion values of $\beta_R = 0.38$ (record to record variability only) and β_{UR} 0.40 (both record to record and material uncertainties) corresponding to collapse (IDR = 10%), the Uncertainty Robustness Index, I_r; the inverse of Uncertainty Robustness Index and modification factor, R_r for strength reduction factor, R can be obtained corresponding different values of k_1 (different levels/severity of seismicity) [2]. The k_1 values corresponding to 2, 3, and 4 (increasing levels of hazard severity) the values or I_r; $1/I_r$ and R_r values are given in Table 1.

More seismically active (severity) locations ($k_1 = 4$) the robustness index has a lower value compared to less seismically active (severity) locations. The I_r; $1/I_r$ and R_r values corresponding to $k_1 = 4$ are found to be 0.88, 1.14, and 0.96 respectively. That is, there is a 14% increase in the structural uncertainties due to the seismic hazard level at the chosen scenario. To account for this randomness, a modification factor of 0.96 needs to be incorporated for the strength reduction factor, *R* while designing the structure.

Table 1 I_r; $1/I_r$ and R_r parameters corresponding to different values of k_1

	$k_1 = 2$	$k_1 = 3$	$k_1 = 4$
I_r	0.97	0.93	0.88
$1/I_r$	1.03	1.07	1.14
R_r	0.98	0.97	0.96

6 Concluding Remarks

A brief overview of past investigations on seismic robustness assessment has been carried out initially. Sequentially basic equations for finding out the Uncertainty Robustness Index have been reviewed and this information is extended to find the modification factor of strength reduction factor of the structural systems. A four-storey two-bay study frame is selected and modeled in the OpenSEES platform with applicable design provisions considering with and without suitable material variability. Additionally, 30 different study models are selected based on the Latin Hypercube Sampling method (structural model with material uncertainty). Afterward, a set of 30 far-field ground motion records are selected and nonlinear time historey dynamic analysis (incremental dynamic analysis) is carried out with and without material variability. Incremental Dynamic Analysis curves for both cases are developed and corresponding dispersions are also found. Using the respective medians and dispersions fragility curves for the two cases are also developed. Finally, the Uncertainty Robustness Index and its inverse and the correction factors for design strength reduction factor found for different hazard levels. It is concluded that when the hazard severity increases corresponding Uncertainty Robustness Index and modification factor for strength reduction factors decreases.

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Mitigation of Progressive Collapse of Multi-Storey Steel Building by Providing Chevron Bracings

Parthav P. Patel and Digesh D. Joshi

Abstract Progressive collapse of any structure causes disastrous failure of structure and significant loss of human lives as well as natural resources. Therefore, it is important to reduce the risk of progressive collapse of structure using various mitigation approaches to avoid disastrous consequences and economic & human losses. In the present study, the effectiveness of chevron bracing is evaluated for mitigation of progressive collapse of 9-storey regular steel moment resisting building. The bracings are provided in the alternate bays of the top storey. The progressive collapse potential of steel buildings is evaluated by following the Alternate Path Method (APM) as specified by U. S. General Services Administration (GSA 2016) guidelines. Linear static, nonlinear static and nonlinear dynamic analyses are performed using SAP2000 software under the middle column removal scenario from the ground floor of the perimeter frame in the longitudinal direction. The demand Capacity Ratio (DCR) of the beams and columns adjoining to the removed column are calculated by using linear static analysis. Nonlinear analyses are carried out to understand the failure mechanism of steel building and to obtain vertical displacement time history at the column removal location. From the results of linear static analysis, it is observed that the presence of bracing members significantly reduces the DCR of beams and columns and thus increases the progressive collapse resistance of the building structure. From nonlinear analyses, it is observed that the provision of bracings contributes to the redistribution of forces and effectively transfers the unbalanced vertical load developed due to the removed column to the adjoining structural members.

Keywords Progressive collapse mitigation · Steel chevron braced frame · Middle column removal

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1 Introduction

Progressive collapse is one of the failure mechanisms, in which failure of a few critical structural elements leads to the collapse of large parts of a structure. It is a chain reaction failure of building members to an extent disproportionate to the original localized damage and also referred to as disproportionate collapse [1]. It is a dynamic failure mechanism that generally occurs under abnormal loading, which results in disastrous consequences and substantial loss of human lives and natural resources. Therefore, it is very important to mitigate the susceptibility of progressive collapse of a building, if it is having a high potential of progressive collapse. Since the collapse of Ronan Point Apartment, London in 1968 due to a gas explosion, many government authorities and local agencies have worked on developing some guidelines for designing progressive collapse-resistant structures. Among these guidelines, the U.S. General Service Administration [2, 3] and Unified Facilities Criteria (UFC) published by the Department of Defense (DoD), United States of America [4] describes detailed methodologies to resist the progressive collapse of RC and steel building structures.

The effectiveness of chevron bracings for the strengthening of 10-storey steel buildings against progressive collapse was studied by Chen et al. [5]. Bracings were provided in all the bays of top storey of building and from the study results, it was observed that provision of bracings significantly increased the potential of building against progressive collapse. Marjanishvili [6] discussed the four analysis procedures, i.e. linear static, nonlinear static, linear dynamic and nonlinear dynamic analyses for progressive collapse analysis of structures. Further, the progressive collapse potential of 9-storey steel moment resisting frame building was evaluated using different analysis procedures [7]. Khandewal et al. [8] analyzed the 10-storey steel braced frame building designed with concentric and eccentric bracings for progressive collapse and it was found that eccentrically braced frame has less vulnerability to progressive collapse as compared to the concentrically braced frame. Naji and Zadeh [9] evaluated the progressive collapse potential of 10-storey steel braced frame building having eccentric bracings and concentric bracings by performing incremental dynamic analysis. The effect of vierendeel action on progressive collapse resistance was examined by Qiao et al. [10] and based on study results, the author proposed a provision of bracings in the top story of building for effective utilization of the vierendeel action. Mahmoud et al. [11] carried out progressive collapse analysis of 5-storey steel moment resisting frame and braced frame building under seismic load using SAP2000 software. From the analysis results, it was observed that the fixity of beam-column connection played important role in the development of catenary action and thus reduce the vulnerability of building against progressive collapse. Mirjalali et al. [12] examined the influence of bracing type and topology on progressive collapse resistance of eccentrically braced frames. Authors have considered different types of bracings such as inverted V, diagonal, combination of V and inverted V, etc. and found that bracings effectively increase progressive collapse resistance. Parikh and Patel [13] presented three retrofitting strategies, i.e. increase in strength, increase in stiffness and increase in both strength and stiffness for mitigation of progressive collapse of 4-storey steel building. Linear and nonlinear analysis methods were adopted for progressive collapse analysis and found that an increase in strength of steel material effectively mitigates the progressive collapse.

In this paper, the effectiveness of chevron bracings is evaluated for mitigation of progressive collapse of 9-storey steel building. Chevron bracings are provided in alternate bays of the top story of the building. Linear static, nonlinear static and nonlinear dynamic analyses are carried out by following GSA 2016 guidelines under the middle column removal scenario from the ground floor of the perimeter frame in the longitudinal direction. The progressive collapse potential of moment resisting frame building is compared with that of braced frame building.

2 General Services Administration (GSA) Guidelines

The U. S. General Services Administration [2, 3] published the guidelines to reduce the progressive collapse potential of building structures. These guidelines are applicable to new and renovated federal buildings and buildings which are going under major modernization. It emphasizes the Alternate Path Method (APM) to ensure the structures' safety against progressive collapse. As per APM, the column should be removed from appropriate locations. The removal extent of the column includes the column removal from the middle of a long side, from the middle of the short side and from corner location. Also, the removal of a column should be considered from other critical locations as determined from engineering judgment. The effect of actions like axial force, shear force and bending moment on the beams and columns need to differentiate either in Force-Controlled Action (FCA) or Deformation-Controlled Action (DCA).

There are three analysis methods suggested in GSA guidelines, i.e. linear static analysis, nonlinear static analysis and nonlinear dynamic analysis. The load combination to be considered for progressive collapse analysis by a specified analysis method is shown in Table 1, where Ω_L and Ω_N is load increase factor and dynamic increase factor, respectively. These increased gravity loads need to be applied in the area adjacent to a removed column, while in the remaining area loads need to be applied as per the specified load combination without considering the load increase/dynamic increase factor.

Table 1 Load combination to be considered for progressive collapse analysis

Analysis method	Load combination	Load increase/Dynamic increase factor
Linear static	Ω_L (1.2DL + 0.5LL)	Ω_L depends on governing m-factor
Nonlinear static	Ω_N (1.2DL + 0.5LL)	Ω_N depends on yield and allowable plastic hinge rotation
Nonlinear dynamic	(1.2DL + 0.5LL)	–

3 Methodology

A 9-storey regular steel building is considered for the present study. The design of structural elements like beams, columns and bracings is carried out using Indian Standard IS 800: 2007 [14]. The progressive collapse potential of moment resisting frame and braced frame building is evaluated by following GSA 2016 guidelines under middle column removal from the ground floor of the perimeter frame in the long side. SAP2000 software is used to perform modelling, analysis and design of steel buildings considered for the study.

3.1 Description of Model

A 9-storey steel building considered for the study has 6-bays in longitudinal direction and 3-bays in the transverse direction. The centre-to-centre distance between columns in the longitudinal direction and transverse direction is 8.25 m and 9.75 m, respectively. The typical storey height of a building is 4.3 m. Chevron bracings are provided in alternate bays on the top storey. The typical floor plan and elevation of the braced frame building are shown in Figs. 1 and 2.

Connections between beams and columns are designed as fully restrained, considering Welded Unreinforced Flange-Welded Web (WUF-W) connections. The support condition of a column at the ground floor level is considered fixed. In braced frame building, chevron bracings are provided in alternate bays of the top storey of the building. The bracings are designed to carry the only axial force and its connection with beam and column is considered as pinned.

Loading on Building

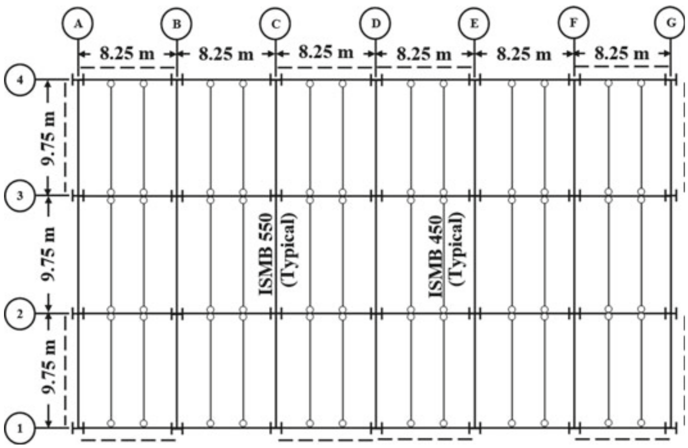

Fig. 1 Plan of braced frame building

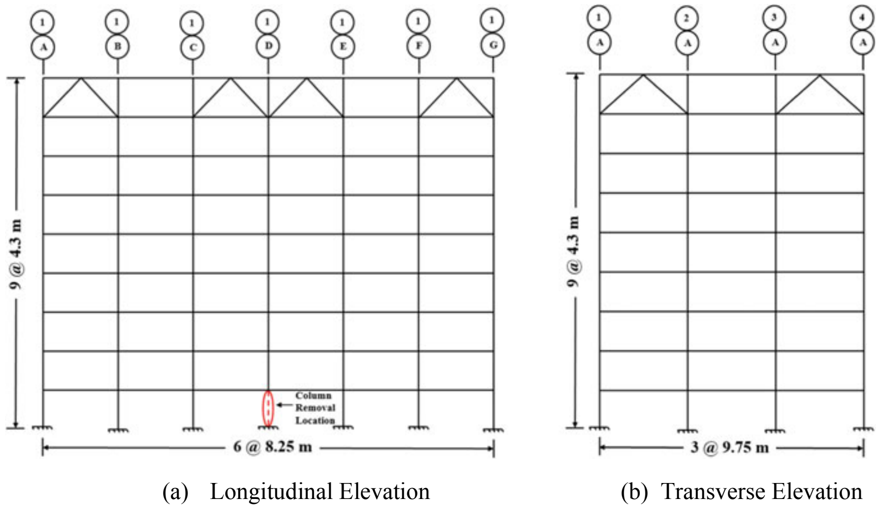

Fig. 2 Elevation of braced frame building

There are two types of loadings, i.e. gravity loads and lateral loads are considered for designing moment resisting frame and braced frame building. Dead load and live load are applied as a part of gravity loading. The dead load includes the self-weight of beams, columns and bracings, the weight of the composite slab and wall load. The thickness of the concrete slab on the steel deck is 90 mm. A Wall load of 19.7 kN/m is considered on perimeter beams except on the roof. The live load of 3.5 kN/m^2 is considered on the floor and the live load on the roof is considered as 1 kN/m^2. The seismic load and wind load are applied automatically in SAP2000 software according to relevant Indian Standards IS 1893: 2016 (Part 1) [15] and IS 875: 2015 (Part 3) [16], respectively, considering that the building is located in Ahmedabad. The designed section of all beams is ISMB 550 on all floors and the designed section of all bracings is SHS 250 × 250 × 12, where, SHS indicates Square Hollow Section of 250 mm width, 250 mm height and 12 mm thickness. Columns are designed as a built-up section with a total depth of 550 mm, 400 mm flange width, 30 mm flange thickness and 25 mm web thickness. The density of steel and concrete is considered as 25 kN/m^3 and 78.6 kN/m^3, respectively. The yield strength of steel material is considered 310 N/mm^2.

4 Linear Static Analysis

The potential of building against progressive collapse is first evaluated through Linear Static Analysis (LSA), as results of the linear static analysis provide an indication about the vulnerability of the building against progressive collapse. Based on the results of linear static analysis, Demand Capacity Ratios (DCR) are calculated at selected locations for beams and columns. For LSA, the load combination of Ω_L (1.2DL + 0.5LL) is considered as mentioned in Table 1, where Ω_L is the load increase factor. The load increase factor is different for force-controlled and deformation-controlled action according to GSA 2016 guidelines.

The moment and shear in the beam are classified as deformation-controlled and force-controlled action, respectively. For columns, the axial force is classified as force-controlled action, but the moment can either be force-controlled or deformation-controlled which depends on the ratio of P/P_{CL}. For $P/P_{\mathrm{CL}} > 0.5$, the moment is classified as force-controlled action and for $P/P_{\mathrm{CL}} \leq 0.5$, the moment is classified as deformation-controlled action, where P_{CL} is lower bound axial compressive strength of the column.

4.1 Determination of Load Increase Factor

The load increase factor for force-controlled action (Ω_{LF}) is 2.00. Load increase factor for deformation-controlled action (Ω_{LD}) is determined from Eq. 1 given below.

$$\Omega_{\mathrm{LD}} = 0.9m_{\mathrm{LF}} + 1.1 \tag{1}$$

where m_{LF} is the smallest of 'm' for any primary beam or girder which is denoted as m-factor or demand modifier. m-factor for steel elements like beams & columns and m-factor for beam-column connections needs to be found out from Table 9–4 of ASCE 41–13 [17]. The m-factor for flexure in beam depends upon the ratio of the width of a flange to twice the thickness of flange and ratio of the depth of web of beam to twice thickness of web. These ratios need to be compared with limits as specified in Table 9–4 of ASCE 41–13 [17] for Collapse Prevention (CP) criteria and calculation of m-factor. The load combination for deformation-controlled action (G_{LD}) is given in Eq. 2.

$$G_{\mathrm{LD}} = 3.773(1.2\mathrm{DL} + 0.5\mathrm{LL}) \tag{2}$$

Calculation of Demand Capacity Ratio (DCR)

From a linear static analysis, the DCR of beams and columns located adjacent to removed columns are calculated. DCR is calculated for flexure for beams, while for column DCR is calculated by considering both axial force and bending moment. The equations to calculate DCR for beams and columns are as follows:

DCR for Beam—Flexure:

DCR in the beam for flexure is calculated as the ratio of the actual moment (M_{act}) to plastic moment capacity (M_P) of the beam section as shown in Eq. 3.

$$\mathrm{DCR\ (Beam - Flexure)} = \frac{M_{\mathrm{act}}}{M_P} \leq \mathrm{Governing}\ m - \mathrm{factor} \tag{3}$$

DCR for Column:

DCR for the column is calculated using various equations given in ASCE 41–13 [17] depending upon the ratio of P/P_{CL}. The DCR for the column is calculated using the following Eqs. 4–6.

$$\frac{P}{P_{CL}} > 0.5,\ \text{DCR} = \frac{P_{UF}}{P_{CL}} + \frac{M_x}{M_{CLx}} + \frac{M_y}{M_{CLy}} \le 1.0 \tag{4}$$

$$0.2 \le \frac{P}{P_{CL}} \le 0.5,\ \text{DCR} = \frac{P_{UF}}{P_{CL}} + \frac{8}{9}\left[\frac{M_x}{m_x M_{CEx}} + \frac{M_y}{m_y M_{CEy}}\right] \le 1.0 \tag{5}$$

$$\frac{P}{P_{CL}} \le 0.2,\ \text{DCR} = \frac{P_{UF}}{2P_{CL}} + \frac{M_x}{m_x M_{CEx}} + \frac{M_y}{m_y M_{CEy}} \le 1.0 \tag{6}$$

where,

$P_{UF} =$	Axial force in Column
$M_x =$	Bending moment in section about *x-x* axis
$M_y =$	Bending moment in section about *y-y* axis
$M_{CLx} =$	Lower bound flexural strength about *x-x* axis
$M_{CLy} =$	Lower bound flexural strength about *y-y* axis
$m_x =$	m-factor for column bending about *x-x* axis
$m_y =$	m-factor for column bending about *y-y* axis

The DCR is calculated for flexure in beams located between gridline C1 and E1 for all stories. DCR for calculated for columns located at gridline C1 and E1. Gridline C1 represents an intersection of gridline C and gridline 1. The comparative graphs of DCR calculated for Moment Resisting Frame (MRF) and chevron braced frame also referred to as Inverted V Braced Frame (IVBF) buildings for beam and column are shown in Figs. 3 and 4 respectively. The vertical line shown in the graph indicates the acceptance criteria for DCR calculated as per GSA 2016 guidelines.

From Fig. 3, it is evident that DCR for most of the beams at a beam-column junction in moment resisting frame building exceeds the acceptance criteria, while in braced frame building DCR at the same location is well within the permissible limit, which indicates that provision of bracings significantly increases progressive collapse resistance of steel building considered for the study. From Fig. 4, it is observed that DCR of a majority of the columns in braced frame building is lesser as compared to moment resisting frame building, which indicates the improved performance of braced frame building against progressive collapse. However, DCR for a column in lower stories exceeds the acceptance criteria because of increased axial force demand in column due to presence of bracings in top storey, which suggests the requirement of more bracing members to fully safeguard the steel building considered for the study against progressive collapse. The DCR for shear in beams and axial tension–compression in bracings satisfies the acceptance criteria for both the categories of building and hence their results are not presented here.

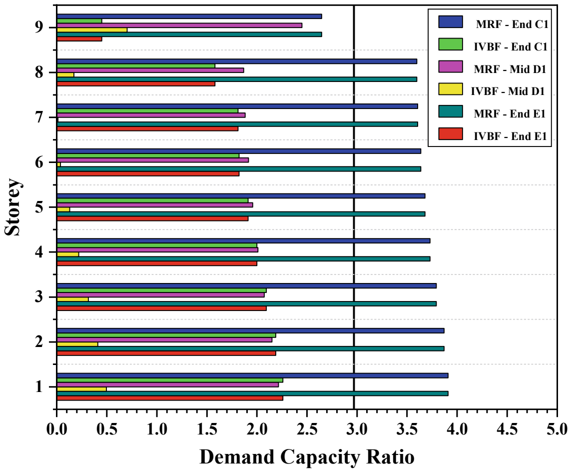

Fig. 3 DCR for Beam-Flexure

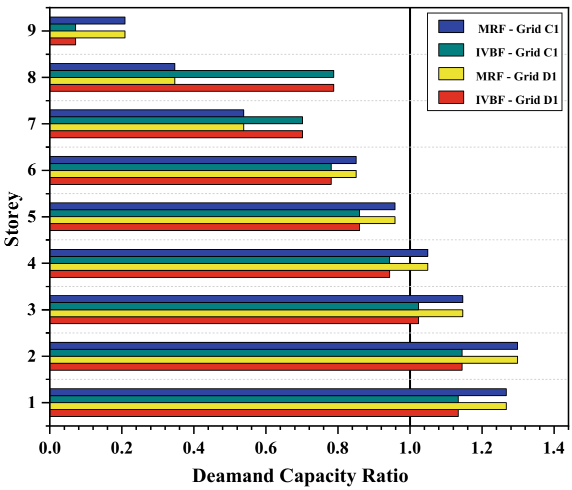

Fig. 4 DCR for Column

5 Nonlinear Static (Pushdown) Analysis

Nonlinear static analysis is carried out in order to find out the collapse load and failure mechanism of the building upon column removal. Generally in lateral load analysis nonlinear static analysis is termed as 'Pushover Analysis' but for progressive collapse, it can be termed as 'Vertical Pushover Analysis' or 'Pushdown Analysis'. The main advantage of this method is that it includes material and geometric nonlinearity. The load combination of Ω_N (1.2DL + 0.5LL) is considered for nonlinear static analysis as shown in Table 1. The important parameter in this load combination is to determine the dynamic increase factor (Ω_N), which depends on support yield rotation (θ_y) and allowable plastic rotation angle (θ_{pra}) for Collapse Prevention (CP) criteria. The dynamic increase factor is determined from Eq. 7.

$$\Omega_N = 1.08 + \frac{0.76}{\left(\frac{\theta_{pra}}{\theta_y} + 0.83\right)} \tag{7}$$

The ratio θ_{pra}/θ_y is the smallest ratio for any primary element, component or connection in the model within or touching the area with increased gravity load. The load combination for nonlinear static analysis (G_N) with dynamic increase factor is given in Eq. 8.

$$G_N = 1.33(1.2\text{DL} + 0.5\text{LL}) \tag{8}$$

The geometric nonlinearity is included in the model by selecting the P-Δ option in SAP2000 software while defining the nonlinear static load case. The material nonlinearity is included in the model by assigning the M3 hinges to beams, P-M2-M3 hinges to columns and P (Axial) hinges to bracings. From the nonlinear static analysis, the graph of the percentage of total load versus vertical displacement is plotted at column removal location as presented in Fig. 5.

From Fig. 5, it is observed that both moments resisting frame and chevron braced frame building attain 100% of applied load without any significant failure. The moment resisting frame building enters into a nonlinear stage, which is evident from the formation of hinges in the beams, while chevron braced frame building remains within an elastic stage, as hinges are not formed in any of the elements. The deflected shape of the moment frame and braced frame building at the final load step is shown in Fig. 6.

From Fig. 6, it is evident that provision of bracings significantly reduces maximum vertical displacement at column removal location, which indicates that bracings

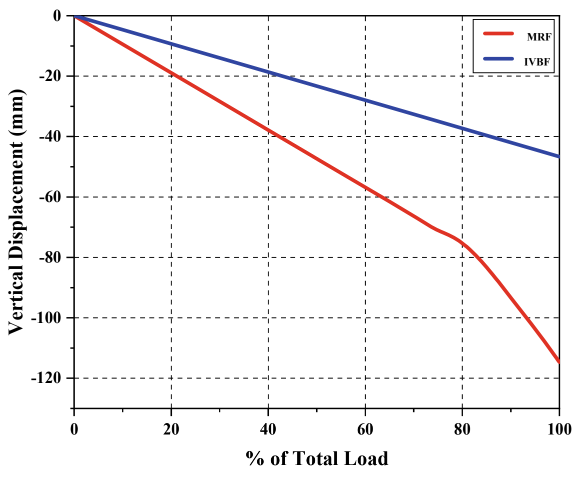

Fig. 5 Nonlinear static curve at column removal location

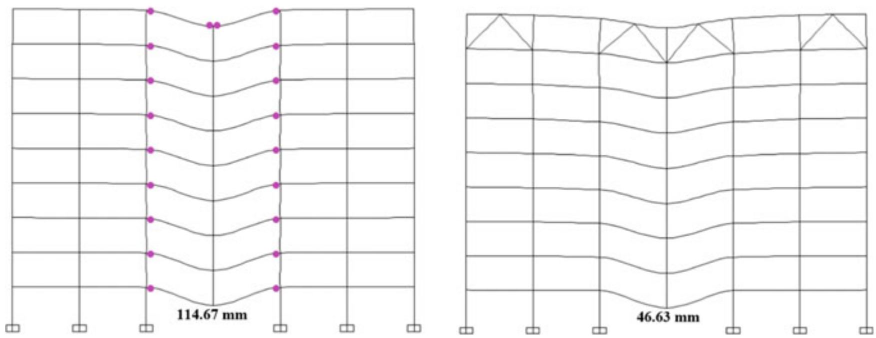

Fig. 6 Deflected shape of MRF and IVBF building—nonlinear static analysis

provide additional load paths to unbalanced load developed because of column removal and thus effectively contributing to progressive collapse mitigation.

6 Nonlinear Dynamic Analysis

Nonlinear dynamic analysis is a more accurate method for progressive collapse analysis because it simulates the actual condition of the building due to sudden column removal. It includes both dynamic effects as well as material and geometric nonlinearity. The load combination of 1.2DL + 0.5LL is considered for nonlinear dynamic analysis as given in Table 1. It does not require any dynamic increase factor because it includes both dynamic and nonlinear effects. The sudden removal of the column from the building results in large deformations, yielding of material, cracking and energy dissipation. For nonlinear analysis, simplified bilinear stress–strain material model is considered with structural steel behaviour of the 3% strain hardening slope of elastic slope.

6.1 Simulation of Sudden Column Removal

For simulating sudden column removal, first, the axial force is measured in the column that is to be removed. It is determined from equilibrium model considering the presence of column that is to be removed using linear static analysis. Subsequently, the column is removed from the model and equivalent axial load is applied as a joint load at the location of removed column. The gravity load including joint load is applied as an initial condition for nonlinear static analysis load case. This condition ensures that structure is stressed before removal of column. Then removal of column is replicated in model through ramp down function in which the axial force as per nonlinear dynamic load case is applied at column removal location. The duration of column removal is less than 1/10th of the time period associated with structural response model for element removal.

Defining the Damping to Nonlinear Dynamic Load Case

The damping plays an important role in the dynamic response of the building after sudden column removal. There is no external damping provided to the building, but the material is having its own damping properties. So, it is important to define the appropriate damping properties of a building while defining the nonlinear dynamic load case. In the present study, the Rayleigh Damping is used for analysis. For this type of damping Rayleigh Damping Coefficient α and β is calculated from Eqs. 9 and 10 respectively.

$$\alpha = \frac{2\omega_i \omega_j}{\omega_i + \omega_j}\xi \tag{9}$$

$$\beta = \frac{2\xi}{\omega_i + \omega_j} \tag{10}$$

Two different natural frequencies (ω_i and ω_j) and damping ratio (ξ) is determined for Eqs. 9 and 10. Modal analysis of the building with the removed column is carried out to find out ω_i and ω_j and the horizontal and vertical mode of vibration are identified. The damping ratio is considered as 2% which is generally used for steel material.

From a nonlinear dynamic analysis, comparative displacement time history is plotted at column removal location for MRF and IVBF building as shown in Fig. 7.

From Fig. 7, it is evident that the presence of bracing reduces the maximum dynamic displacement at column removal location to a great extent. Most of the beams in the MRF building adjacent to the removed column enter into the nonlinear stage but in the braced frame building, all the beams and bracings remain within an elastic stage. The deflected shape of the building for the moment frame and

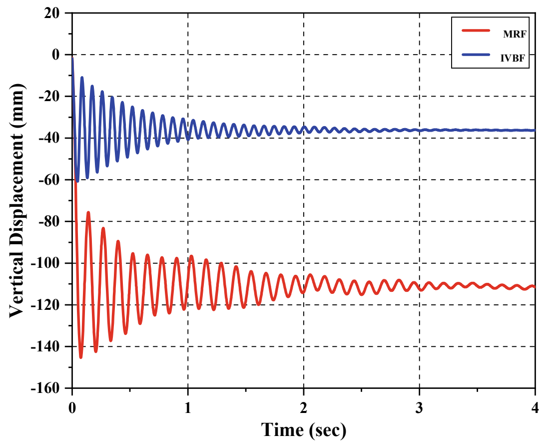

Fig. 7 Displacement time history at column removal location

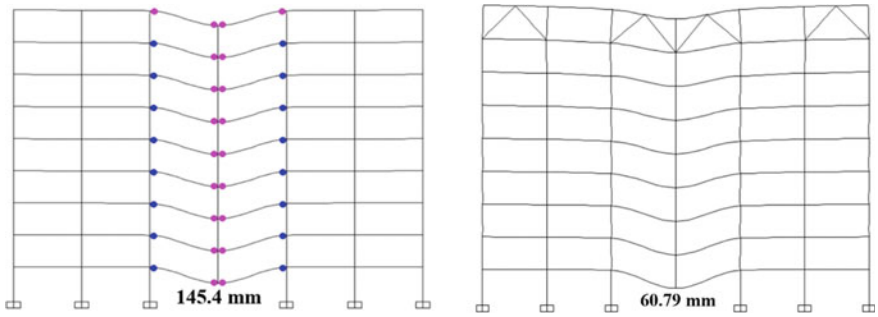

Fig. 8 Deflected shape of MRF and IVBF building—nonlinear dynamic analysis

braced frame building is shown in Fig. 8. The maximum axial force developed in the ground floor column at grid C1 (or E1) in moment resisting frame building (MRF) and chevron braced frame (IVBF) building after column removal is 5545 kN and 7069 kN, respectively.

7 Conclusions

In the present study, the progressive collapse potential of 9-storey regular steel Moment Resisting Frame (MRF) building and the Chevron Braced Frame building which is also referred to as Inverted V Braced Frame Building (IVBF) building is evaluated by following GSA 2016 guidelines. Linear static, nonlinear static and nonlinear dynamic analyses are carried out to evaluate the progressive collapse potential of buildings under the middle column removal scenario from the ground floor of the perimeter frame in a longitudinal direction. Based on the analysis results obtained for steel building considered for the present study, the following conclusions are derived:

- Demand Capacity Ratio (DCR) for flexure in beams for moment resisting frame (MRF) building exceeds the acceptance criteria, while in braced frame building DCR at the same location is well within the permissible limit, which indicates that provision of bracings significantly increases progressive collapse resistance of steel building considered for the study.
- DCR of a majority of the columns in braced frame building is lesser as compared to moment resisting frame building, which indicates the improved performance of braced frame building against progressive collapse.
- DCR for the column in lower stories exceeds the acceptance criteria because of increased axial force demand in the column due to the presence of bracings in the top storey, which suggests an arrangement of more bracing members with different configurations to fully safeguard the steel building considered for the study against progressive collapse.

- Nonlinear static analysis results revealed that both moments resisting frame building and braced frame building are able to resist 100% of the applied load. However, the formation of hinges indicates that beams in the MRF building near removed column enter into a nonlinear stage, while in braced frame building it remains in an elastic stage.
- From the results of nonlinear static analysis, it is observed that bracing configuration considered in the present study reduces maximum static vertical displacement at column removal location by 60% in braced frame building as compared to MRF building, which indicates that bracings are providing alternate load path to transfer unbalanced force developed due to column removal and thus effectively contributes to reducing risk of progressive collapse.
- The maximum dynamic displacement at column removal location from the nonlinear dynamic analysis is reduced by 58% in braced frame building as compared to MRF building.
- Axial force in the ground floor column at grid C1 in IVBF building increased by 28% as compared to axial force in MRF building after sudden column removal.
- The chevron bracing configuration in alternate bays at a top storey, considered in the present study is effective means to increase the progressive collapse resistance under the middle column removal scenario from the ground floor of the perimeter frame in a longitudinal direction.

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Seismic Evaluation, Strengthening and Retrofitting of Schools in Shimla, Himachal Pradesh

Hemant Kumar Vinayak, Shailza Sharma, and Rishabh Singh

Abstract This paper presents strengthening and retrofitting of masonry and reinforced cement concrete buildings of schools in Shimla, Himachal Pradesh. The school buildings were either L-shape or building aggregate constructed with the combination of random rubble stone masonry, brick masonry or reinforced cement concrete. The integrated approach of qualitative assessment with visual inspection, non-destructive testing, masonry structure evaluation with analytical method for in-plane and out-of-plane safety and the method of capacity demand ratio based on elastic analysis and design was used for reinforced cement concrete structures. As per design requirements and fund availability, local retrofit techniques of jacketing stone masonry random rubble walls, splint bandage technique for brick masonry and jacketing of reinforced cement concrete beams and columns were carried out in phases to improve the lateral resistance and bring the structure to the original state. Bracing of trusses was proposed to increase the rigidity of existing flexible roof of masonry structure. The retrofitting and strengthening of building in seismic zone lead to the sensitization of the state disaster management authority about the necessity of developing building resilience of important buildings, thus reducing disaster causality and economic loss. This work highlights the need of seismic evaluation of schools to prioritize the retrofit activity across the network of institutions.

Keywords Seismic zone · Masonry building · Retrofit techniques · In-plane safety · Out-of-plane safety · Jacketing of wall

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1 Introduction

In today's scenario, elementary education is essential, and India has introduced many programs to increase the literacy rate. With the initiatives of Sarva Shiksha Abhiyan for universalization of elementary education, number of school infrastructure in Himachal Pradesh state, India has increased drastically during the last decades [1–4]. However, not much attention has been given to the seismic safety of schools, and unsafe buildings are continuously used for compulsory education [5–8]. The structure of school education system consisting of primary, middle and secondary school and the fund, space and infrastructural requirements varies. Further, the spaces are broadly categorized based on the function of spaces. It is the proper/improper organization and clustering of these built spaces developed by architect, which is further analyzed by civil engineers to make it habitable. Out of various assessments of any building in respect of dead, live, wind and snow load, the seismic load is one such type which needs special attention in the areas where probability of earthquake is high. This is the reason for disaster management authority to examine and improve the school safety policy [5]. There are immense examples of earthquake damaged school buildings in India. World Bank and Asian Development Bank reported in 2001 that Gujarat earthquake damaged more than 11,600 schools, institutes and universities [9]. This number can be less or much high in other earthquakes of India, but that is not the matter of concern. It is imperative that the safety of schools against the disastrous effects of earthquakes is addressed, especially in high risk zones.

The assessment of Sikkim earthquake of September 18, 2011 reported damages to 759 schools [10]. The study of behavior of old historical buildings during August 21, 1988 Bihar-Nepal earthquake revealed the failure of L-shape brick masonry building Madarsa Hamedia, Qila Ghat, Dharbhanga constructed in 1937 with 14 class rooms and verandah corridor consisting of brick masonry arches resting on brick pillars in the front portion of class rooms. The main reason of damage was the failure of verandah arch at one end due to lateral thrust and torsion of building which triggered a sequential failure of arches leading to loss of lives [11]. Janise Rodgers through her study on "Why schools are vulnerable to Earthquakes" showed that physical characteristics of school buildings such as large classroom windows, when combined with inadequate structural design and construction practices, create major vulnerabilities that result in earthquake damages [9]. Especially, buildings in *L*, *H*, *T* and *U* shape with re-entrant corners tend to suffer severe damages at the corners.

Poor construction techniques, implementation of common building design with seismic deficiencies and lack of professional knowledge on seismic resistant construction pose a biggest threat to existing structures in Himachal Pradesh [12–15]. Creating a safe earthquake resistant infrastructural environment is the only key to mitigate seismic hazards. As the codes have been upgraded in later years, many existing buildings in seismic zone turned out to be deficient, and thus, retrofitting becomes essential to reduce damages in existing life line and other important buildings [16–18]. Retrofitting is a prudent option to manage the economic aspects and immediate shelter problems rather than reconstruction. The present study deals with seismic evaluation and strengthening against seismic activities of L-shape school building in Seismic Zone IV. The cases discussed here are some specific examples of how retrofitting or strengthening is done when the data available with the concerned authorities are not up to the mark or are not enough for the calculations which are required for the analysis. In few cases discussed, the year of construction was confirmed from the serving staff members, and few calculations were done after the analysis was done during the site visit. In such situations, engineers and designers use their experience to analyze the condition of the structure and then recommend the required solutions, some innovative methods to make the structures seismically safe. Borri et al. [19] experimentally proved that masonry confinement can be done with the help of steel cords [19]. In the cases discussed here, we used different techniques and methods according to structures condition for making them seismically safe.

2 Structural Analysis of Masonry Buildings

The qualitative assessment and structural analysis of masonry structure were carried out to check the safety of structure against earthquake as per the codal provisions. The evaluation began with visual survey for reviewing the seismic performance of existing building in respect of material deterioration, deficiencies due to improper design and construction, non-implementation of upgradations desired due to revised byelaws. Non-destructive testing was carried out using half-cell for corrosion detection and strength test. After taking site measurements of outer and inner walls length, height and thickness, opening size and location, elevation and plan of the building are developed for the structural analysis and design calculations.

The analysis of masonry building can be either carried out with the kinematic model or equivalent static procedures. Valluzzi et al. [20] emphasized on the kinematic models involving the equilibrium of structural macro-elements for providing better seismic evaluation compared to standard hypotheses based assessment methods [20]. Asteris and Giannopoulos [21] developed a novel methodology for earthquake-resistant design of masonry structural systems, considering modeling a real structure to a robust quantitative (mathematical) representation to be very difficult and complicated task [21]. Parisi and Augenti [22] emphasized that engineering judgement should always be used when assessing whether and how uncertainty propagates from material properties to seismic capacity of an entire masonry structure [22].

The structural analysis of the masonry building compares the in-plane shear stress and out-of-plane bending capacity of the structural member due to applied loading. These evaluations depend on the length, height and thickness of wall and openings, location of openings and density of material used. Shear and bending forces applied to the structural member for design depend on member dimensions, material density and design horizontal seismic coefficient. Masonry buildings should be checked for extreme bending and shear, insufficient anchorage, poor shear transfer between diaphragms and countering walls, pounding caused by interference of adjoining roof levels, connection failure and failure of non-structural components.

2.1 In-Plane Safety Evaluation

The safety check is for extreme bending and shear where stiffness parameter plays an important role for calculating base shear and seismic forces in walls [23]. For stiffness calculation in walls, drawings of elevations of all the walls are prepared with opening locations. The wall is divided into three sections where upper section covers the top most wall pier, second section covers the door openings, window openings and piers, second and third covers the door openings and piers (Fig. 1). Spring model showing stiffness in different piers as per Eq. (1) for the wall pier without opening, Eq. (2) for sections with openings and Eq. (3) for calculating equivalent stiffness in the walls is shown in Fig. 2.

$$R_1 = \frac{\mathrm{Et}}{4\left(\frac{h}{L}\right)^3 + 3\left(\frac{h}{L}\right)} \tag{1}$$

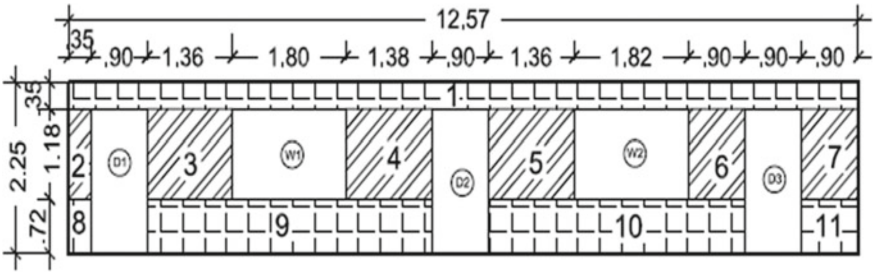

Fig. 1 Elevation of wall 1, first floor

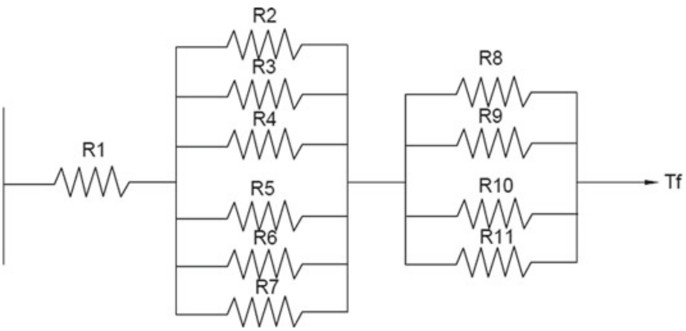

Fig. 2 Spring model of wall 1, first floor

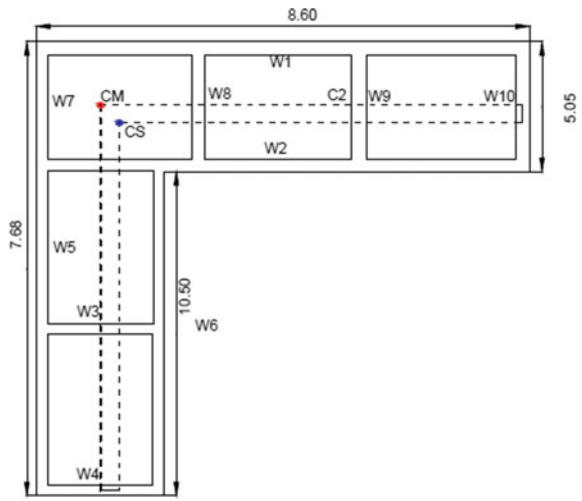

Fig. 3 Position of center of mass and center of stiffness

$$R_2 = \frac{\text{Et}}{\left(\frac{h}{L}\right)^3 + 3\left(\frac{h}{L}\right)} \tag{2}$$

$$\frac{1}{R_{\text{Equ.}}} = \frac{1}{R_1} + \frac{1}{R_2 + R_3 + R_4 + R_5 + R_6 + R_7} + \frac{1}{R_8 + R_9 + R_{10} + R_{11}} \tag{3}$$

where E, t, h and L are modulus of elasticity, thickness, height and length of wall. The equivalent stiffness is calculated by lateral stiffness of building in x- and y-directions. Torsional stiffness, center of stiffness and center of mass are calculated as per Eqs. (4) and (5), respectively (Fig. 3). Static eccentricity in Eq. (6) is calculated as the difference between center of mass and center of rigidity of floor. Design eccentricity is used for torsion calculations at floors. Eccentricity is calculated using static eccentricity values and rotational stiffness as per Eq. (7).

$$X_{\text{CS}} = \frac{\sum_{i=1}^{n} R_i X_i}{\sum_{i=1}^{n} R_i}, Y_{\text{CS}} = \frac{\sum_{i=1}^{n} R_i Y_i}{\sum_{i=1}^{n} R_i} \tag{4}$$

$$X_{\text{CM}} = \frac{\sum_{i=1}^{n} M_i X_i}{\sum_{i=1}^{n} M_i}, Y_{\text{CM}} = \frac{\sum_{i=1}^{n} M_i Y_i}{\sum_{i=1}^{n} M_i} \tag{5}$$

$$e_{\text{SX}} = X_{\text{CM}} - X_{\text{CS}}, \quad e_{\text{SY}} = Y_{\text{CM}} - Y_{\text{CS}} \tag{6}$$

$$e_{d1} = 1.5e_s + e_a, \quad \text{e}_{d2} = e_s - e_a \tag{7}$$

$$R_\theta = \sum_{i=1}^{n} R_{\text{Xi}} X_i^2 + \sum_{i=1}^{n} R_{\text{Yi}} Y_i^2 \tag{8}$$

where R_i, X_i, Y_i, M_i are equivalent stiffness of wall, distance of wall from assumed reference wall in *x*-direction, distance of wall from assumed reference wall in y-direction and mass of the wall, respectively.

To determine the total seismic forces in walls as per Eq. (9), calculation of base shear is done as per Eq. (10), seismic forces due to earthquake are calculated as per Eq. (11) and due to torsion as per Eq. (12). Distribution of wall forces to piers in the wall are done with spring model.

$$T_{fX} = F_{\mathrm{Xi}} + \Delta F_{\mathrm{Xi\,max}}, \quad T_{fY} = F_{Yi} + \Delta F_{Yi\,\mathrm{max}} \tag{9}$$

$$\mathrm{V}_b = \frac{Z}{2}\frac{I}{R}\frac{S_a}{g}B(\varepsilon)W \tag{10}$$

$$F_X = \frac{V_{\mathrm{bx}}}{\sum R_{\mathrm{Xi}}}R_{\mathrm{Xi}}, \quad F_X = \frac{V_E}{\sum R_{\mathrm{Xi}}}R_{\mathrm{Xi}} \tag{11}$$

$$\Delta F_X = \frac{V_{\mathrm{bx}}e_{\mathrm{dy1}}}{R_\theta}R_{\mathrm{Xi}}X_i, \quad \Delta F_Y = \frac{V_{\mathrm{by}}e_{\mathrm{dy2}}}{R_\theta}R_{\mathrm{Yi}}Y_i \tag{12}$$

where Z, I, R, Sa/g, R_{Xi}, R_{Yi}, e_{dy1} and e_{dy2} are zone factor, importance factor, response reduction factor, average response acceleration coefficient, equivalent stiffness in *x*- and *y*-directions, design eccentricity of walls, respectively.

The masonry building has many piers and it is not possible to check the retrofitting solution of all the components of the structural member. Hence, only the slender pier which is more prone to failure and masonry column are designed and checked for safety by calculating the self-weight of the wall, load from the slab, lateral load on the wall, total vertical load on the pier and wall, lateral load on the pier. Lateral load on the pier (F_i) is further used in calculating the moment on pier as per Eq. (13). Net tensile stress (F_t) is computed as per Eq. (14) to design retrofitting for in-plane action. Distribution of net tensile stress and combined compressive stress is checked for slender pier, and tensile force is further used to design the wire mesh as per Eq. (14) for that particular wall. Where $\mathrm{F_i}$, $\mathrm{h_i}$ are lateral load on the pier and height of the pier, respectively. T and f_y are tensile force and characteristic strength of steel, respectively.

$$M = \frac{F_i h_i}{2} \tag{13}$$

$$A_{\mathrm{st}} = \frac{T}{1.33 \times 0.6 \times f_y} \tag{14}$$

2.2 Out-of-Plane Safety Evaluation

This failure occurs due to inadequate anchorage and limited tensile strength and leads to partial collapse of exterior, sometimes cracks at lintel and tops, masonry ejection. Evaluation for out-of-plane safety begins with moment calculations as per Eqs. (15)–(17).

$$A_h = \frac{Z}{2}\frac{I}{R}\frac{S_a}{g}B(\varepsilon) \tag{15}$$

$$P = A_h\,\gamma\,t \tag{16}$$

$$M = \frac{Ph^2}{8} \tag{17}$$

Where A_h, P, γ, t are horizontal seismic coefficient, horizontal force, density of material, thickness of wall.

To carry out stress analysis, self-weight of wall, vertical load from slab, total vertical load (W_t) for unit length are calculated. Compressive stress (f_c) as per Eq. (18) and bending stress (f_b) as per Eq. (19) are checked against permissible stress. In the present study, $f_b - f_c > f_t$ does not satisfy the criterion as per clause 5.4.2 IS 1905. Therefore, seismic band is required for safety against out-of-plane failure. Design of lintel band is done using total moment as per Eq. (20).

$$f_c = \frac{W_t}{t} \tag{18}$$

$$f_b = \frac{M}{Z} \tag{19}$$

$$M_t = \frac{P\left(h_1 + \frac{h_2}{2}\right)L^2}{8} \tag{20}$$

where $h1$ and $h2$ are height of lintel from floor and height of roof from the lintel. Design of band mesh requirement is done by evaluating tensile force, compressive force and moment developed in the band. Balance moment (M) is the difference between total moment and moment of band, which is further used in calculating area of steel.

3 Case Study 1

Himachal Pradesh, a part of NW Himalayas is very sensitive to seismicity, and most of the region falls in Zone IV and Zone V. Many earthquakes of slight, moderate and severe intensity have rocked the state in the past [24]. A comprehensive catalog on earthquake epicenters in Himachal Pradesh has been prepared by Chandel and Brar, and they have identified 533 earthquakes of varying intensities during the period 1800 to 2007 in the state [25]. Out of which, 520 earthquakes have occurred during the period 1964 to 2007, and Chamba district has experienced the maximum number of earthquakes, followed by 99 earthquakes in Lahaul and Spiti, 93 in Kinnaur, 53 in Mandi and 49 in Shimla. The most prominent Kangra earthquake of magnitude 7.8 in 1905 has killed around 20,000 people and destroyed 1,00,000 houses. These frequent earthquakes have affected the infrastructure made decades ago and lag behind in terms of safety parameters. Such old infrastructure requires upgradations with respect to the upgraded codes to meet the safety standards.

The school under study comprised of classrooms and administrative offices in combination of random rubble stone, brick masonry and reinforced cement concrete buildings along with other facilities of toilet, drinking water and assembly ground. The rapid visual survey revealed the necessity to analyze the seismic performance of these building and retrofit them to enhance their performance under seismic loadings. Among the various options available, the retrofit measure of jacketing masonry wall and column is proposed as per the design requirements to be implemented in phase-wise manner. Further, the proposed bracing of trusses would add to the rigidity of the existing flexible roof of masonry structure and resist collapse during earthquake. The necessary repair of non-structural elements and change at the site are also suggested to improve the structural behavior of the building. Although theoretical measures to strengthen every structural/non-structural element of the building can be suggested; however, it is practically not possible to implement all the suggested measures at site with the limited available resources and funds.

3.1 School Background (Government High School, Khalini)

The school that requires retrofitting is in Khalini area of Shimla city of Himachal Pradesh, India (Fig. 4a). Shimla, a hilly city, is in Zone IV and lies between $30^\circ 45' 48''$ and $30^\circ 43' 0''$ N latitude and $76^\circ 59' 22''$ and $78^\circ 18' 40''$ E longitude. The school building consists of two blocks:

(1) Two-story masonry structure with wooden roof truss was constructed around 1980 (Fig. 4b). The building is in L-shape with the single corridor for movement on the concave side and is supported on one-brick masonry column at regular intervals (Fig. 5). The ground floor outer and partition wall were constructed with the combination of dry (Fig. 6a) and wet rubble stone masonry (Fig. 6b). The measured thickness of ground floor walls was 0.5 m. The roof of the ground floor was of 125 mm RCC slab roof. The first floor outer and partition wall was constructed in half-brick masonry of 115 mm. The roof of first floor was a combination with rigid RCC slab over the corridor and flexible wooden roof truss on the classrooms/office. The staircase on one side of L-shape for

a

b

Fig. 4 **a** Govt. high school, Khalini, **b** Two-story masonry building with corridor

climbing to the first floor has water tank supported on the staircase landing roof (Fig. 7). The toilet was constructed adjacently at the back of the building (Fig. 8). The doors and windows were identical in ground and first floor from the front but were different at the back of the building.

(2) Three-story RCC frame building was constructed in around 1990 is another block (Fig. 9). The building has one story as basement which is used as store, ground floor as the faculty room and the first floor as classroom. The access to this RCC block in the first story is common with the masonry block. This three-story RCC-framed structure constructed adjacent to the random rubble masonry structure was measured, and the steel reinforcement used for construction was

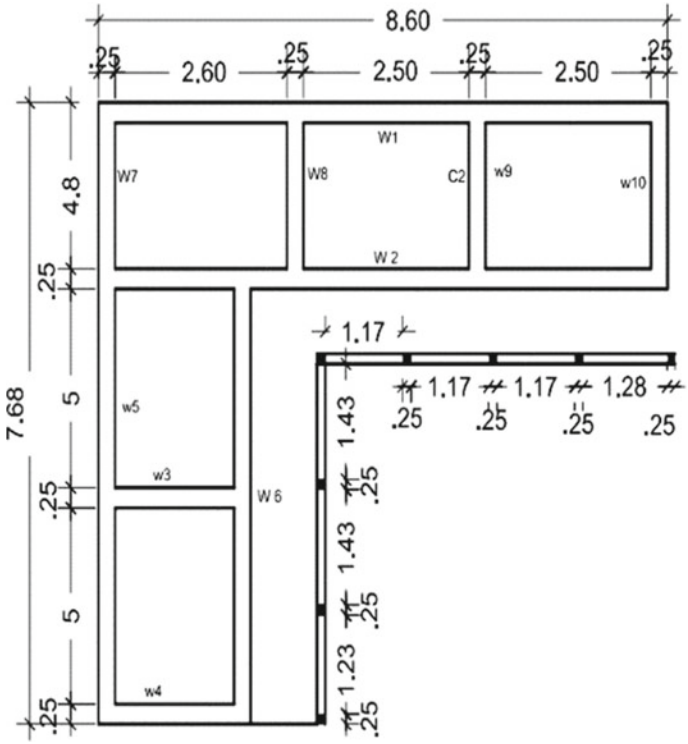

Fig. 5 Plan of first floor of L-shape Building on a scale of 1:200

Fig. 6 **a** Dry rubble stone masonry, **b** Dry rubble stone masonry

Fig. 7 Staircase and water tank

Fig. 8 Toilet at the back of building

Fig. 9 Three-story RCC frame with basement

observed (Fig. 10). The infill walls in the building are constructed with half–brick masonry. Since in case of RCC building, the load is transferred from slab, beam, column to foundation, and the infill wall is non-structural member used to separate two spaces; hence, only the opening size is of importance to calculate the reduced loading of the infill wall not the opening location.

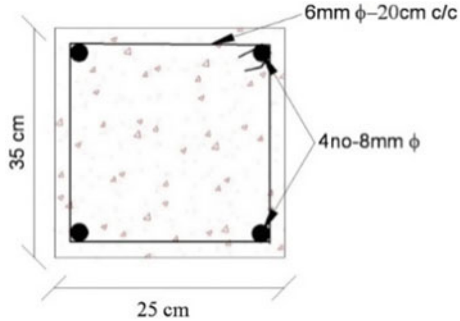

Fig. 10 Reinforcement detailing in column

3.2 *Retrofitting Proposed for Masonry Part of School*

The proposed retrofitting solutions that are either cost-sensitive or time duration sensitive. Vicente et al. [26] worked out the efficiency of strengthening strategies in terms of deformation demands and cost–benefit analysis [26]. Bhattacharya et al. [27] gave the comparison of different methods of retrofitting for unreinforced masonry structures on the basis of economy, sustainability, feasibility and provided a useful insight [27]. Based on the qualitative analysis and structural assessment, proposed retrofitting solutions as per IS codes are:

(1) Random rubble masonry is always weak in shear whether dry or wet and dry random rubble are even weaker than wet random rubble masonry (Fig. 11a). For design purpose, such wall is considered as zero shear wall (Fig. 11b). So, to increase the shear strength of random rubble masonry wall, the inner and outer wall portions are tied together (Fig. 12), and reinforced cement concrete jacketing was carried out on both sides of the room. In the present case, the retrofitting solution of jacketing the ground floor wall both from inside and outside with 75 mm thick RCC wall and reinforcement of 8 mm @ 225 mm is proposed as shown in Fig. 13.

(2) The first floor of the building constructed with half-brick wall random rubble masonry is weak in shear. The solution in this case is jacketing of wall from

Wall a Wall b (b)

Fig. 11 Random rubble masonry wall **a** Shimla school **b** Damaged during Bhuj earthquake

Fig. 12 Through elements in wall [28]

Fig. 13 Jacketing of random rubble masonry

both sides with 75 mm thick RCC wall and reinforcement of 8 mm @ 225 mm is proposed as shown in Fig. 14. Alternative proposal was to demolish the first floor and reconstruct as per the codal norm. However, such procedure would have resulted in impaired functionality of the school building.

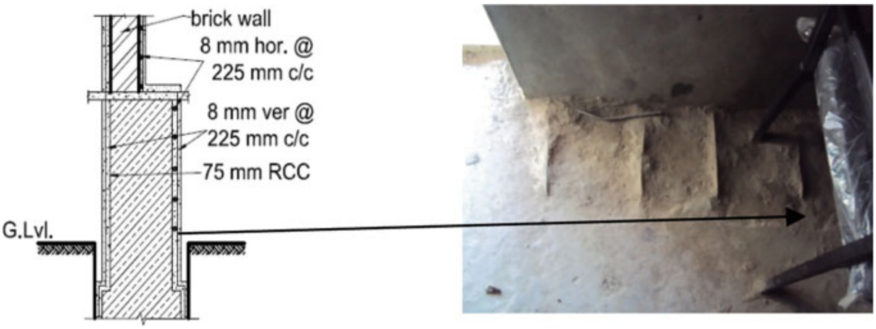

Fig. 14 Detail and GF wall jacketing reinforcement bent at floor level

Fig. 15 Cross-bracing in wooden roof truss

(3) The roof of the two-story random rubble masonry building is built with the wooden roof truss consisting of only rafters, purlins, intermediate tie member, thus making the roof a flexible part of the building. To convert the roof from flexible to rigid structure, proposed solution to install cross-bracing of size 38 mm × 38 mm × 3 mm between trusses is carried out as shown in Fig. 15.

3.3 Structural Analysis and Retrofitting of RC Part of Building

The structural analysis of RCC building consisted of idealizing the three dimensional building into beam, column and slab, applying appropriate live loading as per IS 875 (Part 2), i.e., 3 KN/m2, seismic loading as per IS 1893 ($Z = 0.36$, $I = 1.5$, $R = 5$, Sa/g = depending on modal calculations) [16, 29]. Based on the bending moment and shear force due to applied loading, required reinforcement has been proposed. The construction of RCC building was carried out in the year 1990, which was before the upgradation of IS 1893:2016 and IS 13920:2016 [16, 17]. The structure lacks strength against seismic forces, and analysis of RCC frame is carried out to determine the deficiency in the reinforcement of beam and column (Figs.16a, b and c).

The analysis of RCC frame and masonry building has been done independently to check the individual strength and behavior. It has been found necessary to isolate both the structures by breaking the continuity slab between the two buildings and seal the joint with flexible material like sealant and metal plate to prevent ingress of water.

4 Case Study 2

The school building (Fig. 17a) in which the retrofitting is proposed consists of three blocks. The analysis of the building is carried out to check if the structure is safe against earthquake as per the codal provision. In case the structure is unsafe, the analysis is again carried out with possible retrofitting solution.

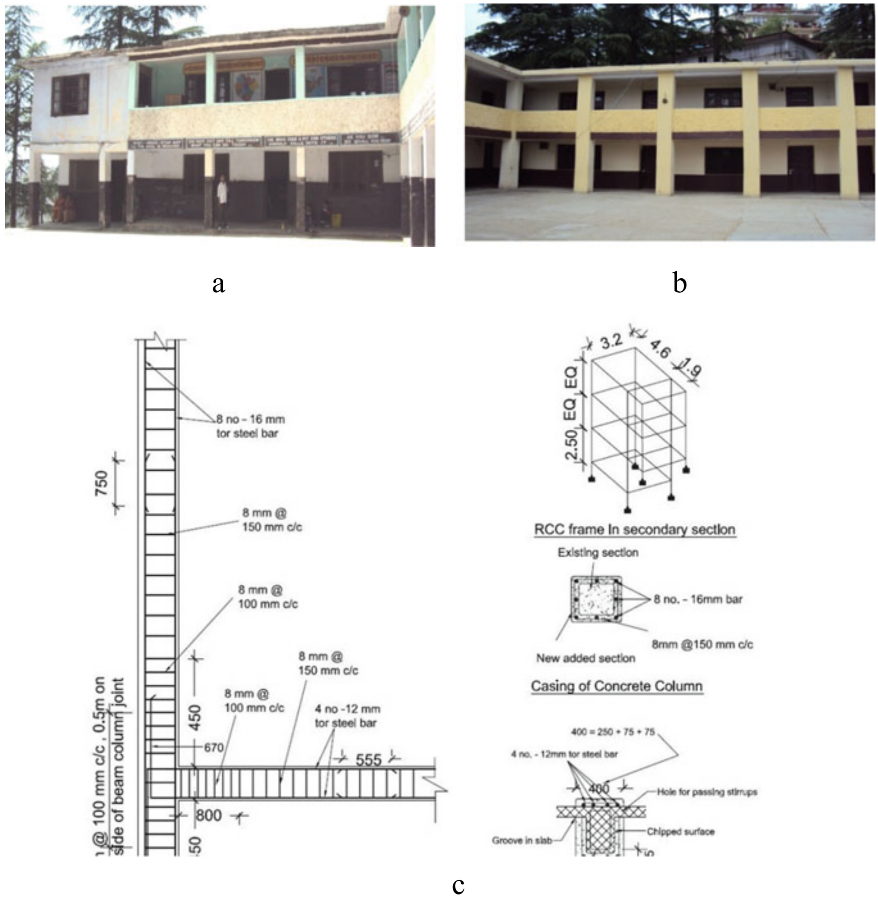

Fig. 16 Reinforced cement concrete frame details

4.1 School Background (Totu School)

Block A—One-story composite masonry structure is with wooden roof truss and MS sheet covering constructed around 1963 (Fig. 17b). The block consists of store, administrative office, principal office, physics laboratory, kitchen for mid-day meal, classroom and staff room. The building is rectangular with an additional room as store (Fig. 17c) in line with single corridor available for movement in the block. The corridor roof is supported on one and a half brick masonry columns at regular interval (Fig. 17d). The story is constructed with half-brick masonry. The outer and partition walls of the rectangular block were constructed with 0.5 m thick dressed stone masonry (Fig. 17d, Fig. 17e) and one-brick thick masonry wall, respectively. The door and windows in the front wall and the windows at the back wall are place almost at regular intervals (Fig. 17f). The site measurement consisting of outer and

Fig. 17 **a** GSSS Totu, **b** Aerial view, **c** Story in Block A, **d** Corridor, **e** 0.5 m outer wall, **f** Windows at regular interval

inner wall length, height and thickness, opening size and location was carried out. The elevation and plan are then generated as per site measurement.

(2) Block B—Two-story composite masonry structure with wooden roof truss is constructed with ground and first floor in around 1975 and 1977, respectively, (Fig. 18a, b). This block consisted of only classrooms. The building is rectangular with the ground floor outer and partition wall constructed as observed with 0.5 m wet random rubble stone masonry (Fig. 18c, d). The ground floor roof of reinforced cement concrete slab is 100 mm thick (Fig. 18e, f). The first floor outer wall is half-brick masonry, i.e., 115 mm (Fig. 18g). The roof is supported on wooden truss at regular interval of approximately 1.5 m (Fig. 18h). The staircase for climbing to the first floor is common and attached with Block C.

(3) Block C—Two-story composite masonry structure with wooden roof truss is constructed around 1990 (Fig. 19a, b). This block consisted of sport room, classroom and computer laboratory in the ground floor and classroom cum presentation room in the first floor. The building is rectangular with the ground floor outer and partition wall constructed as observed with 0.5 m dressed stone masonry as well as with half-brick wall (Fig. 19c, d). The roof of the ground floor is of about 100 mm thickness, constructed with reinforced cement concrete slab (Fig. 19e). The first floor outer wall is constructed in half-brick masonry, i.e., 115 mm with one-brick column at approximately 3.5 m interval (Fig. 19f). The roof is supported on wooden truss at regular interval of approximately 1.5 m (Fig. 19g). The landing in front of first floor entrance is common with Block B. (Fig. 19h).

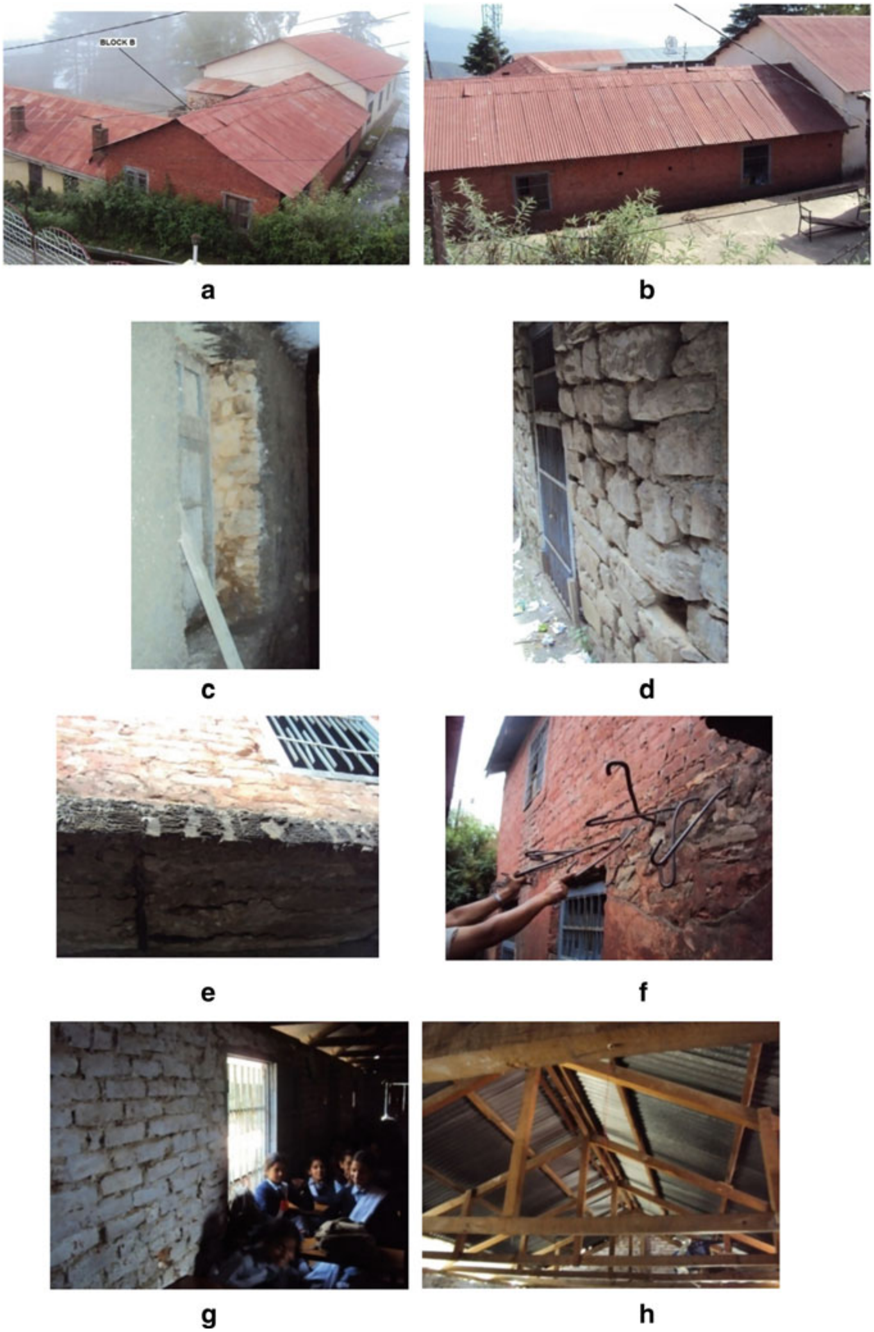

Fig. 18 **a** Block B—an aerial view, **b** Back side view, **c** Wet random rubble masonry, **d** Wall thickness 0.5 m, **e** Slab thickness 0.1 m, **f** Slab reinforcement, **g** First floor wall thickness 0.115 m, **h** Roof truss

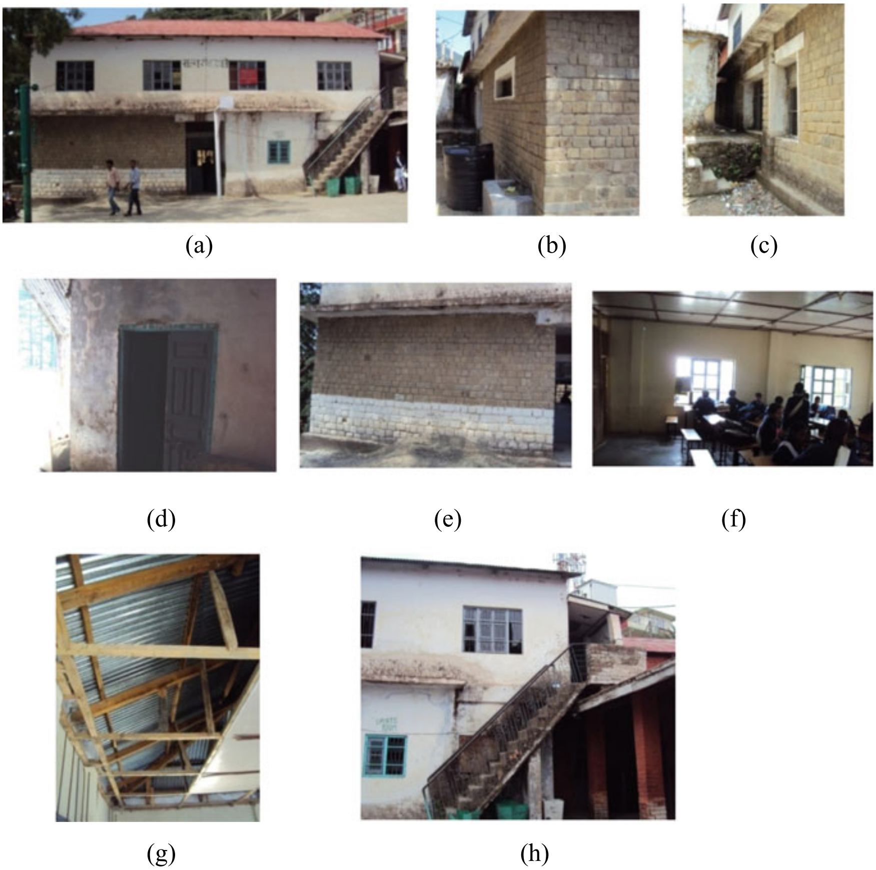

Fig. 19 **a** Block C—front view, **b** Back side view, **c** Wall thickness 0.5 m, **d** Wall—0.115 m, **e** Slab thickness 0.115 m, **f** First floor wall 0.115 m, **g** Wooden roof truss, **h** Common staircase and landing of Blocks B and C

4.2 Retrofitting Solutions Proposed and Carried Out

Deficiencies in the building and their retrofitting solutions if possible adhering to Indian codal provision are:

(a) Block A—This block is unsymmetrical due to high aspect ratio of approximately 5:1, and the storeroom is in line with corridor. Such buildings are always more susceptible to earthquake damage due to the torsion that gets developed due to unsymmetrical shape and mass about both the longitudinal and transverse axis. The building should be symmetrical about the two axes for reduced torsion effect. The removal of storeroom and creating separation joint in the block to reduce the aspect ratio are one solution. However, in the present case, such solution was not possible. Hence, the deficiency of unsymmetrical building plan will persist even after retrofitting. Since the wall was dressed stone masonry, hence, it is capable of taking the shear, tensile and compression stress. After calculation, it has been observed that all the walls are safe in out of plane bending and in-plane shear based on the permissible limit as specified in the Code 1905, expect for one wall in which the jacketing of the pier between windows have been proposed. The masonry corridor columns were acceptable based on the calculation; however, as a precautionary measure, the retrofitting of the masonry column with nominal reinforcement has proposed. During earthquake, the failure of column would be a hindrance for evacuation of the children. The replacement of two wall of storeroom constructed with half-brick masonry with one-brick masonry along with the removal of window, shifting of entry door of storeroom to the center of wall, was done (Figs. 20a, 20b). The wooden roof trusses are flexible diaphragms; hence, cross-bracings were introduced in between the two consecutive rafters (Fig. 20c). The chimneys projecting over the roof in vertical line with the fireplace have been in use, once the wood has been used to keep the room warm during winters (Fig. 20d). However, such chimneys are not in use now. Hence, remove the chimneys and

(a) (b) (c) (d) (e)

Fig. 20 **a**, **b** Store room window to be removed, **c** Corridor roof, **d** Chimneys to be removed, **e** Corridor roof subjected to leakage

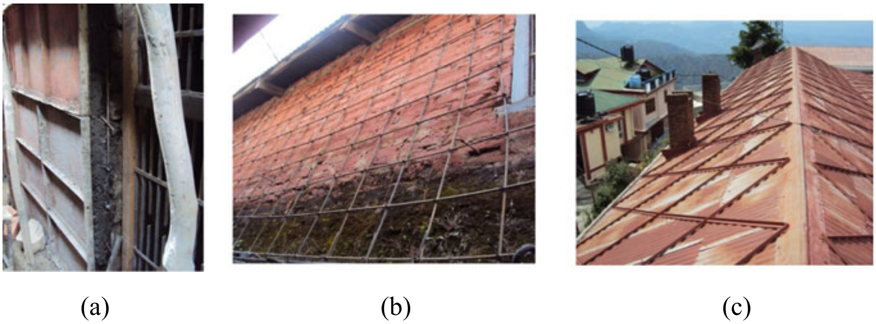

Fig. 21 **a**, **b** RCC wall both inside and outside **c** Roof truss with cross-bracings

plug from top. The end of the building adjacent to Block B is prone to leakage in the corridor at some places accordingly the sealing of roof to be carried out (Fig. 20e).

(b) Block B—This block has been constructed keeping one wall of Block A as common instead of independent entity, thus introducing the deficiency of non-separated building unit. The ground floor with random rubble masonry is a wall with zero shear resistance, and the first floor with half-brick masonry is deficient in respect of earthquake resistance. Hence, the jacketing is from ground to first floor with 75 mm thick reinforced cement concrete wall on both inside and outside the building with reinforcement of 8 mm @ 225 mm c/c. The walls of the building, which are inaccessible from outside, were retrofitted with 150 mm thick RCC wall with reinforcement 12 mm @ 300 mm c/c (Fig. 21a, b). The wooden trussed roof was cross-braced to reduce the flexibility of the diaphragms and, thus, reduces excessive displacement; however, the chimneys were not removed (Fig. 21).

(c) Block C—This composite block with the ground floor constructed having dressed stone and half-brick masonry and first floor with half-brick masonry was deficient in-plane shear and out-of-plane bending. The jacketing of deficient piers and replacement of half brick with full masonry were carried out. In case of first floor with half-brick masonry, jacketing from outside was not possible; hence, 150 mm thick RCC wall with reinforcement 12 mm @ 300 mm c/c was proposed and carried out. During earthquake, the RCC wall will resist the applied in-plane shear and out of plane bending; however, there is every possibility of half-brick wall collapsing; to prevent sudden failure, jacketing with wire mesh from outside was proposed and carried out.

5 Issues in Retrofitting

1. Though L-shape buildings are more prone to earthquake damages due to irregular configuration, they can be transformed into two independent rectangular blocks using separation joint. However, separation of existing L-shape building into simple blocks is not possible, and this deficiency will persist even after retrofitting.
2. Although chipping of walls is carried out before the jacketing of the wall; however, binding of new concrete with old plaster is an issue of concern.
3. Jacketing of RCC column and beam with reinforcement and concrete requires breaking and reconstruction of wall. Such activity leads to weakening of infill and apparently reduced stiffness.
4. To achieve absolute strengthening and retrofitting of the building structures, codal guidelines are always an issue due to lack of funds.

6 Conclusions

1. The deficiencies in the masonry buildings are due to inappropriate knowledge with the grass root construction workers.
2. The buildings with random rubble masonry can be retrofitted without hampering the functionality of the building.
3. The demolition of building can be avoided, and the structures can be upgraded keeping in sight that every department does not have excessive fund to create a new structure every time.
4. The imposed fund limitations limit the retrofitting to the extent required.
5. The hill state has their own constraints of material transport and availability of experienced workers for achieving efficient retrofitting work.

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Seismic Strengthening and Retrofitting Techniques and Solutions for an Existing RC Frame: An Overview

Praveen Anand and Ajay Kumar Sinha

Abstract Seismic performance of any existing reinforced concrete (RC) buildings is greatly influenced by the inadequacies associated with the design, stiffness, existing performance demands, degradation of materials due to aging, due to use over time and several other factors. It has been found that a large number of RC structures lacks the existing seismic demand and clearly reveals an urgent need to upgrade and strengthen this deficiency. A significant amount of investigations has been carried out to strengthen and retrofit the existing RC structures. The outcome of the researches was increased strength, stiffness, and ductility of the retrofitted structures. This article aims to present an overview of different techniques and practices available to strengthen the existing and damaged structures. The paper also presents the research gaps and identifies the scope of future research along with providing outlines for future direction of research in the establishing effective retrofitting solutions.

Keywords RC structures · Strengthening · Retrofitting jacketing · Bracing · FRP

1 Introduction

India is a country highly prone to earthquakes. Many devastating earthquakes had occurred here causing heavy losses of life and property. It is not the earthquakes which brings devastation, but it is the failure of faulty structures which does so. Ever since the devastating earthquakes which occurred in India whether it be the Bihar Nepal earthquake in 1934 or the Bhuj earthquake in Gujarat in 2001, there has been a constant revision and up gradation of seismic codes in India. Keeping in mind statistical records of their occurrence and the probabilities of their reoccurrence, there is a very urgent need of seismic evaluation of the existing RC framed buildings

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many of which has been designed for gravity loads and hence assess their seismic performance and accordingly retrofit them to increase their capability of withstanding severe earthquake forces.

Seismic retrofitting and up gradation of structures is an area over which various works and research has been done till now. Due to constant revision and upgradation of seismic design codes, it becomes very necessary in a country like India that there must be detailed assessment of the existing RC framed structures which has been mainly designed on the basis of gravity loads disregarding the effects of earthquake loads. Retrofitting of buildings shall comply with the design criteria and procedures of these standards for achieving the performance-based retrofitting. Retrofitting is one of the most suitable options to make an existing inadequate building safe against future probable earthquakes or other environmental factors.

In this paper, attempt has been made to present an overview and address the innovative, advantageous, and cost-effective retrofitting techniques for different types of existing reinforced concrete structures. The paper presents the researches and findings carried out across the globe on advanced retrofitting and strengthening techniques such as RC jacketing, steel jacketing, FRP jacketing, steel bracing system, and addition of shear walls.

2 Retrofitting Techniques

2.1 RC Jacketing

There are several techniques available for seismic retrofitting. One of the earliest and foremost method of retrofitting of structures is concrete jacketing. In this method, the cross section of column is increased with added reinforcement thus making the columns strong enough to withstand the forces. Concrete jacketing has been proved to be very effective method in seismic retrofitting which helps in the conversion of strong beam weak column into a strong column and weak beam thus inducing the formation of hinges in beams and not in columns during the formation of mechanism [1]. With this strong column weak beam principle, shear capacity of the column also gets enhanced. The fundamental advantage of this technique is that it increases the shear and flexural capacity and is easy to construct. Secondly, a substantial increase in ductility as well as stiffness of the section can be obtained depending upon the amount of reinforcement and type of concrete added in the jacket [2].

In general, it has been seen that column failures have caused significant damage to the RC structure. Studies done over the past earthquake damages, it was found that shear failures, shear cracks, and column shortening were observed in column members. The primary function of jacketing is to increase the load-carrying capacity of the structural elements against lateral loads. In the study conducted by Anand et al. [3], finite element analysis of a RC jacketed column model was carried out by providing 100 mm thick jacket, and a significant increase in the axial load-carrying capacity of the column was observed. Similarly, different researchers have used different thickness of jacket based on their suitability as enough research data is not available that can clearly validate the thickness to be used [4–8]. Another important factor influencing the performance of RC jacket is the interface treatment. Studying the bonding behavior between the existing column and the jacket layer is a critical phenomenon. Till date, enough research has been done to predict the influence of interface treatment, but a clear demonstration of the effect in yet not clearly depicted. The influence of surface preparations, the use of epoxy resins, as well as steel connectors was conducted [9–11]. Post analyzing the test results, they concluded by the use of bonding agents or steel connectors monolithic behavior of jacketed member can be established even without increasing the surface roughness. However, among the method adopted for surface preparation, sand blasting and notched surface were found to be the best treatment to achieve higher bond strength. Despite of the fact that sand blasting and notched surface were effective in achieving a good bond strength, a clear demonstration to predict the behavior is at the interface which is yet to be resolved. Based upon the results of previous studies, proper guidelines should be prepared for interface treatment (Fig. 1).

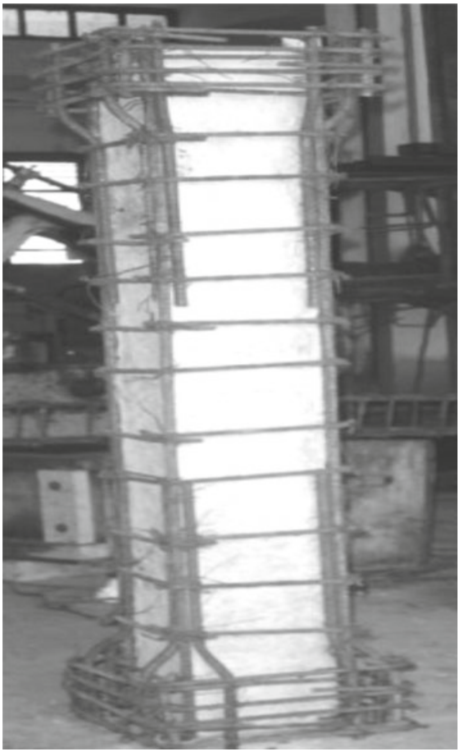


Fig. 1 RC jacketing of column [8]

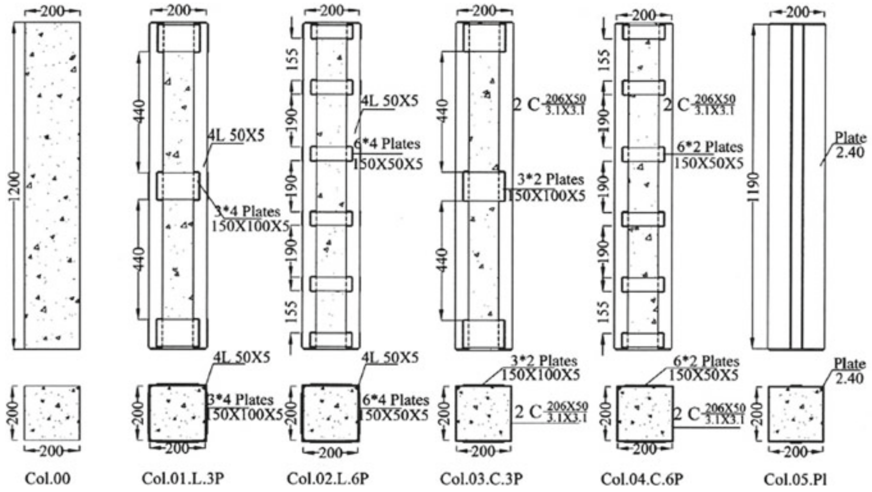


Fig. 2 Specimen configuration details [13]

2.2 Steel Jacketing

Steel jacketing refers to a method in which the column section is encased with the steel plates and the gap in between is filled with non-shrink grout. The encasing steel plates may be of full length or partial length of the encased column. Anchor bolts along with end stiffeners are also used to facilitate and simplify the connections. As compared to the other methods of jacketing, steel jacketing offers two most remarkable advantages (1) the amount of transverse reinforcement that can be provided can be increased significantly and (2) the spalling off of the shell concrete can be prevented which is considered to be the main reason for bond deterioration and buckling of longitudinal bars [12]. Behavior of RC columns strengthened with steel jackets was also studied by Belal et al. [13]. Main parameters that were studied included shape of the strengthening system, Size and shape of the batten plates. Seven specimens were constructed which was divided unstrengthened specimen with two units and strengthened specimen with five units as shown in figure. The experimental program was again verified with the finite element modeling in ANSYS which were in good agreement with each other. It was concluded that with the application of steel jacketing technique, load-carrying capacity increased up to 20% and the mode of column failure shifted from brittle to ductile (Figs. 2 and 3).

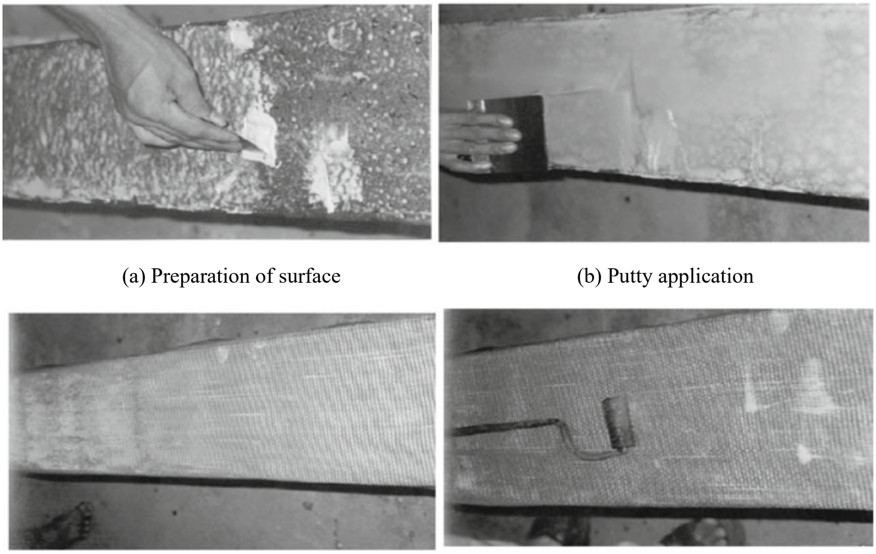
2.3 Fiber Reinforced Polymer (FRP) Jacketing

In the last two decades, due to extensive search for an alternative strengthening system, FRP composites have come out as a reliable material to be used for the

Fig. 3 Strengthened RC column with steel jackets with 3 battens, 6 battens, and complete steel plating [13]

retrofitting objectives. FRP jacketing is considered to be one of the most popular seismic retrofitting methods across the globe. This is because of the multiple advantages associated with it over the existing conventional method such as less labor work, ease and speed of installation, original geometry remains undisturbed, high strength-to-weight ratio, less curing time, significant fatigue strength, minimum disturbance to the occupants during installation. However, FRPs are relatively costly and its fire resistance properties must be addressed. Secondly, there exists an uncertainty regarding the durability of FRPs in their long-term performance. Strengthening of existing RC columns is one of the most common application of FRP as it increases the strength and ductility. While using FRP sheets for strengthening purposes, prime considerations include preparation of surface for existing concrete, anchorage of FRP sheets, numbers of FRP layers and their orientation. In order to apply FRP laminates, the surface should be made free from dust and oil, the resin should be applied uniformly to the prepared surface and entrapped air shall be removed before the resin sets (Fig. 4).

To analyze the effect of increasing the number of layers several researchers performed experimental analysis to study the behavior of axially loaded square and rectangular column confined by glass fiber reinforced polymer (GFRP) wrapping using different numbers of GFRP layers [15]. For increased number of layers of GFRP, better confinement was achieved which resulted in improvement of axial load-carrying capacity of the reinforced concrete column, and the ductility of columns was also improved. The increase in load-carrying capacity of a RC column with single layer of GFRP wrapping with rounded corners was studied by Anand et al. [16]. Finite element analysis was done using ABAQUS software where the ends of



(a) Preparation of surface (b) Putty application

(c) Layering of coated sheets (d) Removal of entrapped air

Fig. 4 Installation of FRP sheets procedure [14]

column to be retrofitted was rounded. It was concluded that rounded corner FRP jacket is able to provide better confinement to the concrete.

2.4 Steel Bracing

Steel bracing is highly efficient and economical method of retrofitting, and it has been seen that this method can resist the horizontal forces in a framed structure. The seismic performance of the building gets improved with the bracing as the lateral stiffness gets enhanced. This method of strengthening of existing structures is applicable for both steel as well as concrete structures. Similar to the other methods, bracing also has several advantages such as enhancing the strength, stiffness and ductility, low cost and time of installment, less increase in dead load as compared to other methods (Fig. 5).

Seismic retrofit of RC frames with steel bracings was first introduced by Sugano [18]. Several analytical and conceptual studies regarding bracing was done by Baduox et al. [17]**.** In their study, frames with short and weak column were studied, and it was found that bracing can be used to specifically target the strength and stiffness deficiencies, but inelastic buckling of braces should be avoided. Analytical study was carried out based upon the previous experimental research in which an RC frame was retrofitted with steel bracing system. The modeled frame shows how the axial load

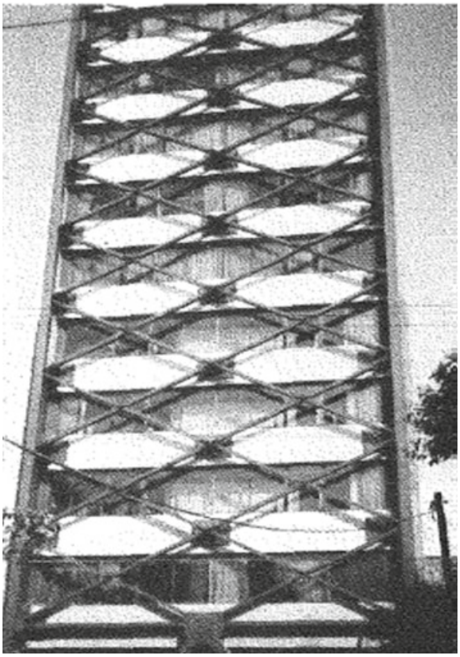


Fig. 5 Steel braced building [17]

P coming from top on the column gets distributed among the two braces B1 and B2, thus reducing the tendency of column failure as shown in Fig. 1. P being the vertical load and H is the horizontal load. Effectiveness of seismic retrofitting comprising buckling restrained braces placed along the perimeter of the multistoried frame was studied by Sarno et al. [19]**.** Seismic performance of existing and retrofitted five-story RC structure was evaluated by Dwaik et al. [20] implementing two retrofitting techniques viz RC jacketing and eccentric steel bracing. Structural response was evaluated using static nonlinear and dynamic analysis in SAP2000. It was concluded that steel bracing turns out to be improved choice for retrofitting of medium height buildings (Fig. 6).

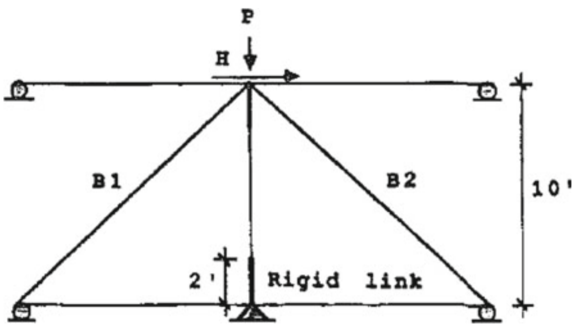


Fig. 6 Forces acting on a brace frame [17]

2.5 Addition of Shear Walls

In order to increase the stiffness and lateral strength requirement of building, shear walls can be provided which has proven to be quite effective in controlling the inter-story drift reducing the forces on columns, etc. Shear walls are generally placed between two columns, and they are rectangular in cross section. Columns on two sides of shear walls behave as two boundary elements which significantly increases the strength of wall in flexure and shear. Application of shear walls involves removal of existing partition walls and replaces with shear walls instead [21]. With such application, shear walls are able to withstand lateral loads along with reduction in building displacement as a result RC frames has to resist less amount of lateral loads. In order to examine the effectiveness of shear walls, finite element analysis was carried out by Ismael et al. [22] in which a three-story residential RC building was selected for response against earthquakes. SAP2000 was used for the analysis, and the building was subjected to wind load, seismic load along with gravity load. The building was reanalyzed for the aforementioned load combination with the addition of 5 mm, 7 mm, and 10 mm thick shear walls. It was observed that the moment in beams and columns were reduced considerably, thus reducing the seismic vulnerability of the building.

Wall section may fail in flexural tension or flexural compression. In order to prevent a brittle failure by sudden fracture of tension reinforcement the cracked flexural strength of the wall section shall be greater than its uncracked flexural strength. As the wall is subjected to gradual increase in moment, initially it behaves as an uncracked plane concrete section till the cracking moment is reached. On further increase in moment, the reinforcement alone resists all the tension. Walls not having boundary elements of increased thickness, vertical reinforcement shall be concentrated at the ends of the walls for better flexural strength.

3 Conclusion

The survey offered in this article focused on the different experimental as well as analytical programs with innovative seismic techniques available. Due to the updated design manuals and code of practice, urgency for retrofitting of seismically deficient structures has come out as a definite requirement. From the review presented in this paper, it can be clearly observed that each of the retrofitting techniques was able to enhance the strength of the existing structure. Similarly, each technique contributed in enhancing the stiffness and ductility. In addition to increasing the overall capacity of the existing buildings, these retrofitting techniques also contribute to sustainability. However, each method has its own advantages and disadvantages associated with it. Therefore, prior to application of any of these techniques, proper assessment of the current state of the existing structure is essential. All the techniques mentioned above relies on the experiments done by various researchers. Therefore, appropriate guidelines should be prepared in the form of codal provisions to apply these techniques reliably.

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Integrated Site Investigation Procedure (ISIP) for Managing Infrastructure Development

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Abstract A new approach for landslide risk management and evaluation is presented in this paper as an Integrated Site Investigation Procedure (ISIP) and Landslide Maintenance Management by the application of the Geographic Information System (GIS). This latest technique would identify and generate land zoning for incorporation into the Malaysian Land Planning System for construction approval. ISIP can help develop cost-effective approaches for subsurface studies, site planning, sampling methods, data analysis, simulation prediction, and mitigation strategies for the particular areas. Non-technical decision-makers are often required to help determine the condition before taking necessary technological steps. The main objective of the research was to analyze, improve and evaluate desk studies and mapping methods that would allow fast and accurate landslide evaluations to be exercised from national to site-specific for the management of infrastructure planning. The suggested methods for risk identification and evaluation in this paper would promote risk determination by a potential empirical study of landslide hazards using a case study carried out in the district of Jeli, Kelantan, Malaysia. This latest approach is useful for the evaluation of landslide hazards for land suitability requirements, particularly in Malaysia.

Keywords Risk analysis · Landslide · Methodology · And System

1 Introduction

Environmental catastrophe is a common problem in many areas worldwide where citizens and the environment are in dispute. The susceptibility of the populated

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regions to natural disasters is partly contributed by a series of decades of spatial planning policies that failed to consider adequate account of geo-risks in making decisions land of use planning and development. Therefore, it is important to establish more effective methodologies for integrating the reduction of natural disasters into spatial planning, particularly from national to site-specific. This paper discusses the strategies for tackling geohazard risk management in Malaysia by integrating the Strategy, Planning and Development Program by Integrated Site Investigation Procedure (ISIP) and Slope Management by incorporation of the Geographic Information System (GIS) and satellite imagery. Site Inspection Protocol (ISIP) and Slope Control through the application of the Geographic Information System (GIS) and the Virtual Reality (VR) Technology were used as a method procedure to collect all data and resources that include geohazard risk map. This will assist in the implementation of cost-effective approaches that can mitigate measures for the particular location.

1.1 Integrated Site Investigation Procedure (ISIP)

Integrated Site Investigation Procedure (ISIP) was developed in the context of the Basic Law for Physical Planning in Malaysia [1–10]. The development process was initiated by the Town and Country Planning Act 1976 (A172), which stipulates two approval phases, i.e., the Structure Plan (Sect. 7(3)) and the Local Plan (Sect. 12). Construction management and the consent process require consultancy and advice from multiple relevant bodies before land transfer authorization or the planning authorization [Act A172 Sects. 18 and 19(1)]. Development may occur only after Sect. 22 authorization or extension, following Sect. 24(3). The Town and Country Planning Department (TCPD), the Public Works Department (PWD), the Drainage and Irrigation Department (DID) and the Water Works Department (WWD) shall all coordinate local governments until approved. Legislation A133 was used to approve design during the management planning process. The reporting requirements, plan deposit, and construction and job inspection information was also included. Regulations require the local government to enact and enforce the Building Regulation. The primary objective of ordinance A133 is to ensure that people in or around buildings, buildings, or structures that may be affected have a reasonable level of health and safety. In terms of soil engineering, the central legislation governs the 1992 Earthworks By-Laws in which Erosion and Sedimentation are subject to Sect. 2(6)(a); Sect. 2(6)(e)(ix) slope stabilization; Sects. 2(8)(9), 2(12) and 2(11) provide the framework, and structural completeness set out in Sect. 85A of the A133 Act. By-Laws 1992 [3], Sects. 4(70(a)) & 4(70(b)) of Act A133 emphasize the need for inclusion of site and soil inspection as factors for geohazard risk assessment. No specific site inspections are, however, made, such as the type of investigation provided and the scope of the site research. Section 2(8) and Sect. 4 of Earthworks By-Laws 1992 currently only recommend detailed inspections of the site for piling status, end bearing load capacities; piling based on the unique surface characteristics. Some details are overlooked, including the vulnerability of each implementing partner to land erosion and landslide during development, and the level of detail required for earthworks to increase.

1.2 *Integrated Site Investigation Procedure*

In the course of the construction process, two modes of site investigation were incorporated which are the physical and resource planning site investigation (Fig. 1) and the construction site investigation (Fig. 2). The convergence mechanism of these two forms of site investigation would be a positive step to ensure that all information is handled and used accordingly to the legal framework and in the planning process of Malaysia integration. The process of integration is illustrated in Fig. 3. The integration process between the physical and resource planning development (Fig. 1) and the engineering construction site investigation (Fig. 2) provides a framework for the integrated site investigation. The Integrated Site Investigation Procedure (ISIP) comprised of accumulated general information and it becomes more detailed as shown in Fig. 4. Integrated site investigation procedures are divided into three different categories such as planning the site investigation, urban development investigation, and specialized investigation and mitigation. Each type of inquiry is unique, and the scope and detail of the proposed work are specified to minimize the possibility of misunderstanding between planners, engineers, geologists, developers, and decision-makers [11].

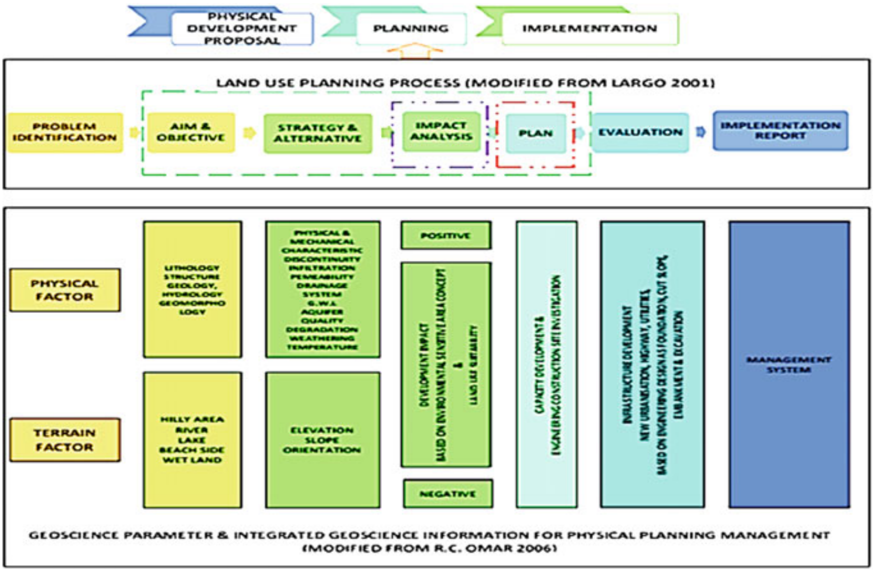


Fig.1 Site investigation for physical development planning [11]

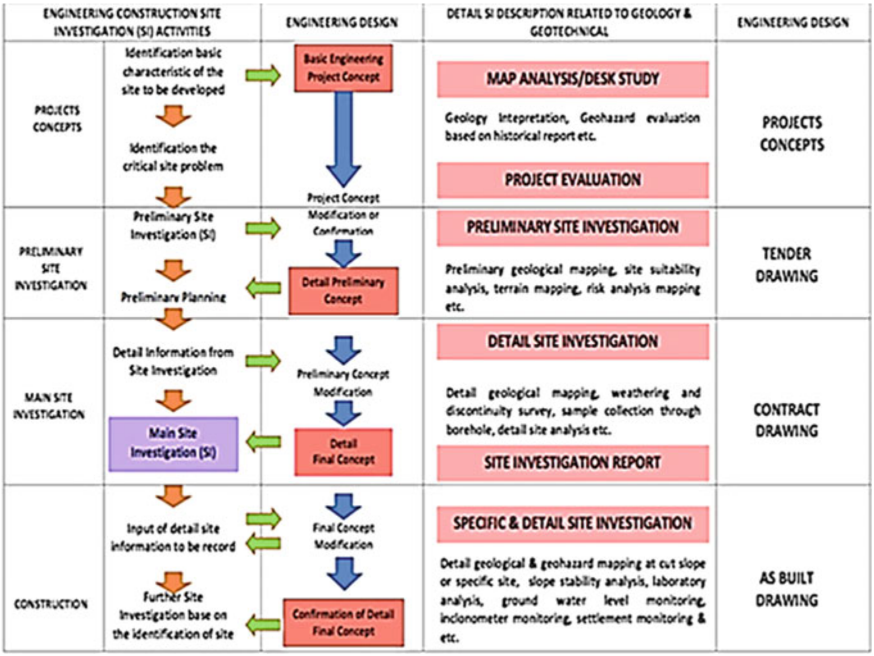


Fig.2 Engineering construction SI (Adapted from [11–14]

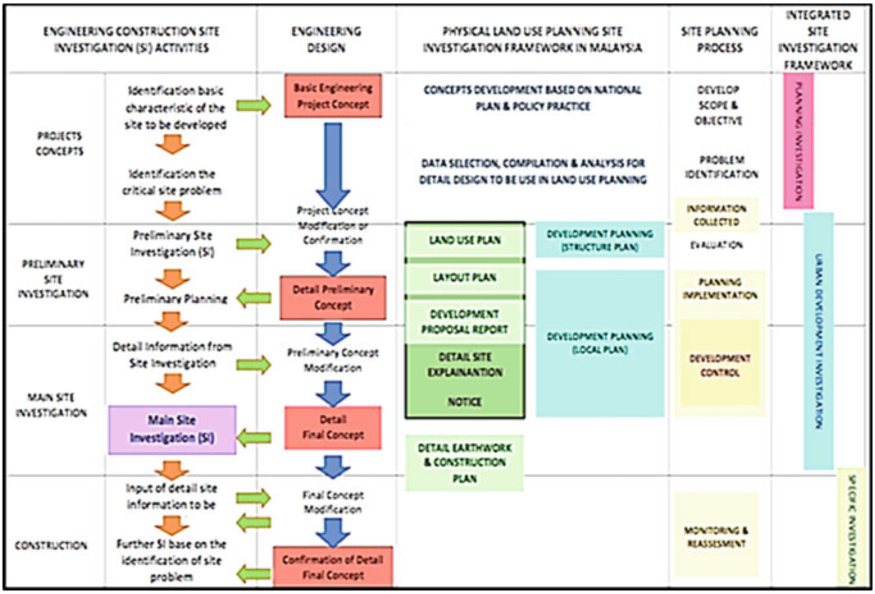


Fig. 3 Integration process from Figs. 1 and 2 [11–14]

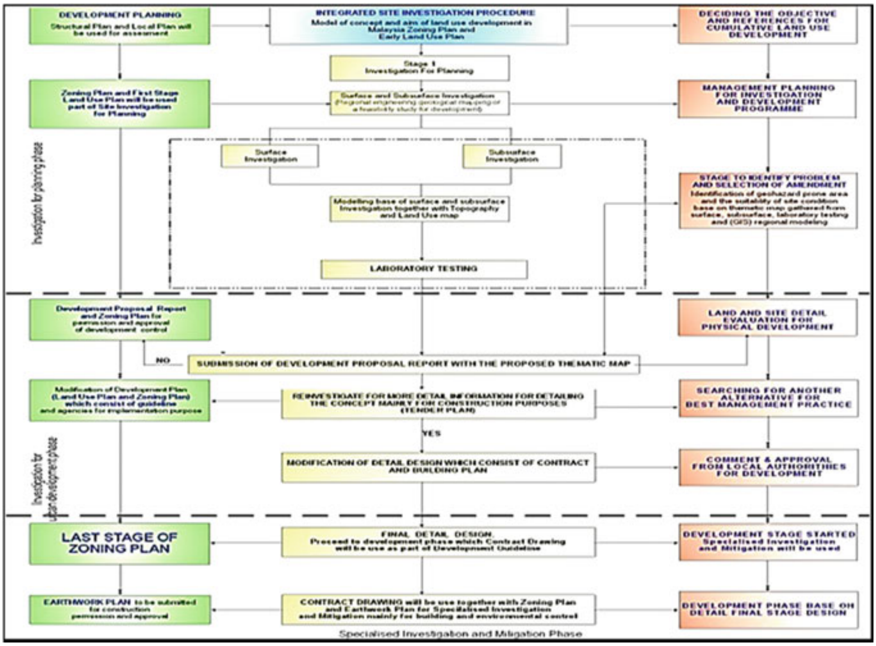


Fig. 4 Integrated Site Investigation Procedure [11–14]

The planning investigation provides comprehensive details on the geotechnical conditions of the site (Fig. 4). The planning investigation is the first stage in the assessment of a specific area for town planning purposes consisting of regional engineering geological mapping or feasibility study for the development of a particular site where information from local engineering geological mapping is not available [11–14]. This assessment is essential for the investigation of large areas specifically more than 1000 ha. The planning investigation consists of the planning of the future development of the urban regions, the assessment of the natural resources of areas intended for future growth, the conservation, and prevention of the natural resources, and the identification of geological problems at an early phase of the planned development for the environmental impact assessment of urban areas. Data from the first stage procedure are used to determine and formulate the objectives and references to cumulative land-use development [1, 11]. Investigation for urban development is required for an area of more than 10,000 ha in size. The evaluation of the planning investigation is used to assess the feasibility of using the site for urban development. The objective of this investigation is to identify and map the detailed engineering of the geological and geotechnical conditions of the terrain to define the regions of geotechnical constraint, as well as the implementation of development control and approval by local authorities [11–13]. The urban development investigation is further subdivided into two types, based on the size of the area considered, as the approach and execution of the geological and geotechnical engineering investigation of small regions differ significantly from that of larger areas. Specialized site investigation and mitigation (Fig. 4) generally depend on the final design plan for the engineering construction site investigation [11–14]. These investigations are more specialized and detailed and will provide full information on the design of the ground base for the zoning and earthwork plan.

1.3 Development of Thematic Map Using Integrated Site Investigation Procedure

The Integrated Site Investigation Procedure (ISIP) allows the collection of geoscience details to be considered at all stages of planning. During the planning investigation, the collected geoscience information will be used to formulate priorities and objectives, and also to define site issues based on optimum land use and environmental quality protection, which is the critical thrust in the development of physical land use in Malaysia [1]. At this stage, geoscience data is used to determine the suitability of the site. The map produced is suitable to determine the capacity of the site based on development needs [15–18]. Types of thematic maps produced by using general geological data such as rock, soil, weather profile, and rock discontinuity are tabulated in Table 1.

Overlaying various geoscience parameters can generate map varieties intended to assist developers in the determination of construction suitability and capacity that is incorporated into the zoning plan. The maps generated at this point are used as a criterion for planning guidance. Geoscience parameters such as rock type, topography, slope, elevation, and degradation can produce a detailed land classification map, as shown in Table 1. Geohazard potential risk map can be created from the integration of general geological information, topographic and geological profiles with physical and mechanical properties using a classification based on environmentally sensitive areas concepts as stated in Act 172. The geohazard potential risk map provides useful information in the development proposal report for obtaining development approval. The data acquired from the investigation of the urban development site (Planning Stage and the Specialized Investigation & Mitigation) for the redevelopment or development of new townships can be used as a guide for structural plans, local development plans, and reporting layouts.

1.4 Thematic Maps in Physical Development Plan

Integrating thematic maps into the planning process helps local governments develop and implement strategies in order to reduce the risks from multiple natural hazards [15–20]. Planning may also combine mitigation with development and growth management programs to establish integrated approaches that efficiently address

Table 1 Geoscience information parameter for thematic map using ISIS [11–13]

Geoscience parameter	Integrated site investigation		
	Investigation for planning	Investigation for urban development	Specialized investigation and mitigation
Rock type *Soil type* *Weathering* *Discontinuity data*	·Basic map ·Site suitability map ·Engineering geology map ·BH point map ·Site constraint map ·Construction material map ·Rock head map	·Bedrock thickness Map ·Weathering thickness Map ·Transported Soil Thickness Map ·Reclamation Map ·Site Map ·Foundation Map ·Slope Stability Map ·Site Contamination Map ·Erosion Potential Map ·Wetland Conservation and Constraint Planning Map ·Detail Geotechnical Classification Map ·Detail Site Constraint Map	
Geomorphology *Topography* *Slope* *Elevation*	·Topography map ·Isopach elevation map ·Terrain Classification Map ·Landform map	·Detail Terrain Classification Map ·Detail Engineering Geological Map	
Physical properties *Mechanical properties* *Degradation*	·Historical Geohazard Map	·Geohazard Potential Risk Map	

natural hazard mitigation and prevent competing outcomes, such as high-density urban development in a hazard-prone region. Planning can also target and mitigate the identified vulnerabilities as posing the highest risk to a proposed development area or redevelopment area. Integrating thematic maps into the land-use planning process is a step towards reducing risk by mitigating natural hazards. During initial land use, decision-making and construction are much simpler and more cost-effective than having to retrofit, change or upgrade existing infrastructure to withstand risks.

1.5 Example of Integrated Site Investigation Procedure

In this paper, a sample of geological information obtained from Jeli, Kelantan was analyzed to produce different types of thematic maps using the Integrated Site Investigation Procedure in the Geographic Information System (GIS) platform as tabulated in Table 2. Topography, slope, and geomorphology as shown in Figs. 5 and 6 were analyzed using investigation for planning to form Terrain Classification Maps as illustrated in Fig. 7. This example was used to provide information in an inquiry for planning (for large areas, typically greater than 10,000 ha), investigation for urban

Table 2 Thematic map from ISIS in physical development plan [11–14]

Malaysia physical planning process		
Current practice	Proposed implementation to include thematic maps from integrated site investigation	
National Physical Plan (Record Geohazard Event)	Geohazard ESA Site Identification	
State structure plan (Geohazard general risk map)	Geohazard that has occurred Overall Geohazard Area Determine Special Risk Area (areas identified as Special Area Plan for Risk Disaster	Basic Map DEM Map Engineering Geology Map Terrain Classification Maps Site Constraint Map Historical Geohazard Map
Local plan and special area plan (Geohazard strategic risk plan)	Geohazard Risk Area disasters follow specific risk levels Type of development that suitable for Geohazard Area Geohazard risk area that not suitable to develop	Slope Stability Map Erosion Potential Map Detail Geotechnical Classification Map Site Suitability Map Detail Terrain Classification Map Geohazard Potential Risk Map
Planning permission brief (Geohazard risk evaluation)	Identify methods to control specific Geo Hazard Identify activities that suitable in a particular area	Activities for control Geohazard based on Potential Risk Map

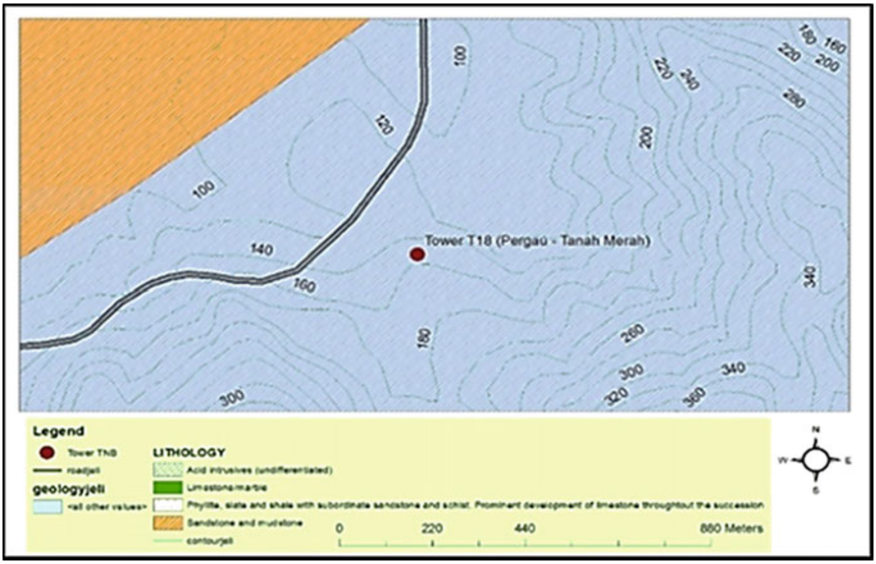


Fig. 5 Topographic map of Pergau, Tanah Merah, Jeli

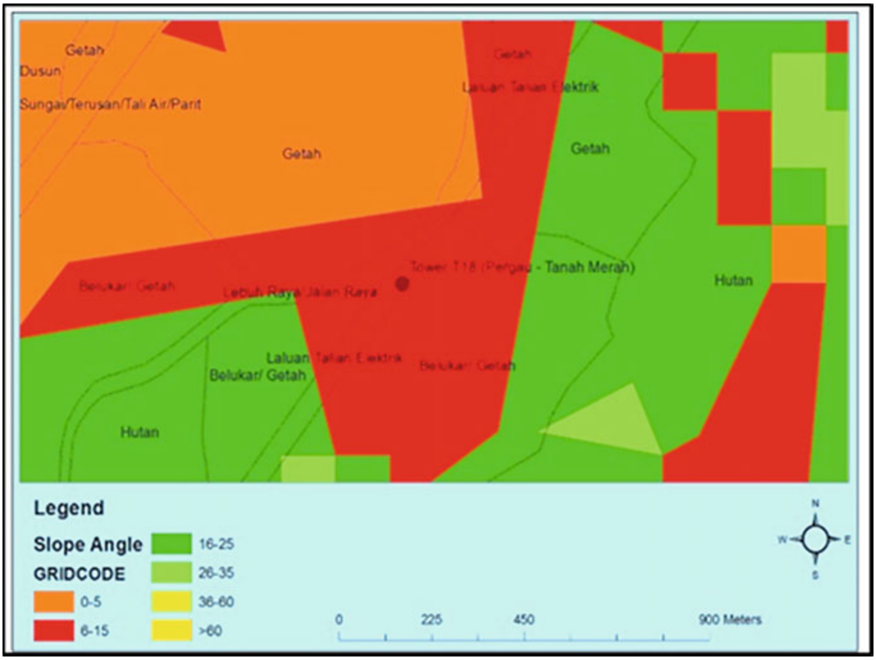


Fig. 6 Slope map for Jeli, Kelantan

development (an area more a less than 10,000 ha in size), and specialized investigation and mitigation (site-specific and more detail typically represent for less than 5000 ha).

Terrain Classification Map (Fig. 7) was used in the State Structural Plan for determining particular risk areas, geohazards that have occurred, and overall geohazard area. Terrain Classification Map consists of four criteria:

Zone 1 Very Low-Risk Level; Terrain in-situ hills slope angle from >15°

Zone 2 Low-Risk Level; Terrain in-situ—slope 15–35° with existing signs of erosion together with geological sensitive material or colluviums at the foot slope. The label (1lm1,2Hg2, 2E31, 3B31, 3D21) indicated that minor sheet erosions have occurred at these areas based on the slope gradient at foot slope or drainage slope.

Zone 3 Moderate Risk Level; Terrain in-situ slope from 25 to 35° without erosion sign and terrain in-situ-slope 15–25° with existing signs of erosion of sensitive geological material or colluviums. The classification is depicted as 4A21 in Fig. 7.

Zone 4 Terrain in-situ—slope > 35° with existing signs of erosion; terrain in-situ-slope 25–35° with existing signs of deterioration of sensitive geological material or colluviums.

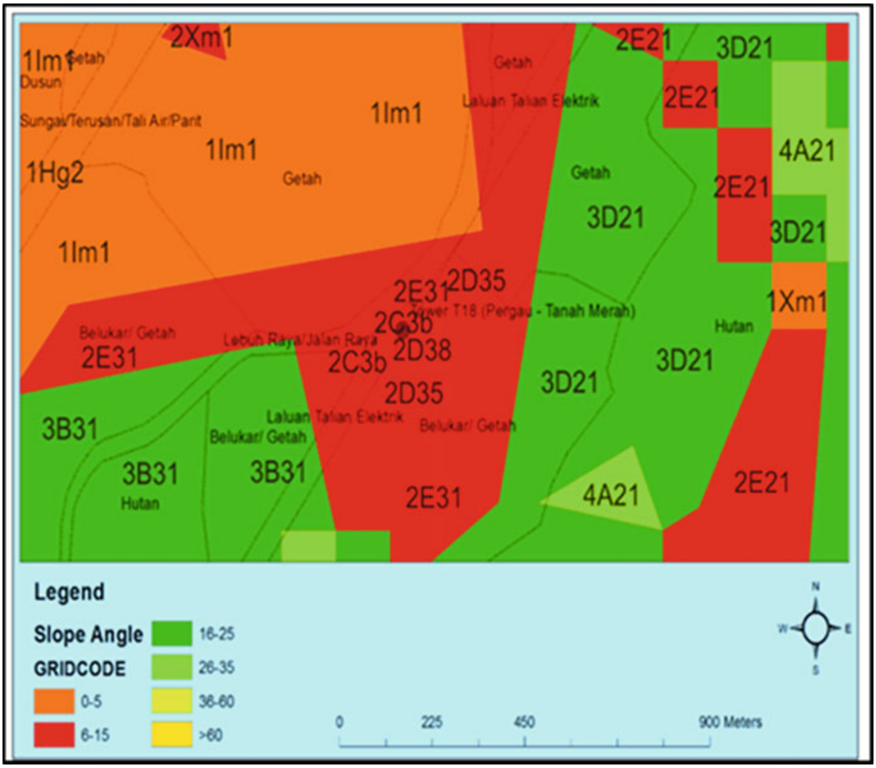


Fig. 7 Geological Terrain Classification Map of Jeli

Three zones were identified in the study site, marked as Zone 1, Zone 2, and Zone 3. Zone 2 was classified as 1lm1, 2Hg2, 2E31, 3B31, and 3D21, indicating that the site has a natural slope comprising of soil and rock material of which minor sheet erosion has occurred at foot slope or drainage slope. Zone 3, located mostly at hillcrest was covered by soil with little sheet erosion. Terrain classification map and topographic map overlay were translated to form the suitability maps using Investigation for Urban Planning which can be incorporated in the local plan. Zone 1 and Zone 2, less than 300 m in Jeli (Fig. 5) can be developed whereas Zone 1 and Zone 2 exceeding 300 m can be considered as tourism park areas. Zone 3 with the slope angle less than 20° and the site to be developed in this zone less than 20% can be constructed after the agreement with mountainous technical committee. However, 80% of the area in Zone 3 needs to be considered as the green zone. The suitability classification related to the development of a zoning plan based on criteria type of development that is suitable for geohazard area is compiled in Table 2.

Information gathered through Integrated Site Investigation Procedure such as landslide history (Fig. 8) overlaid with a topographical map, geological map, soil map, and terrain to produce Jeli Landslide Hazard Map is shown in Fig. 9. Jeli

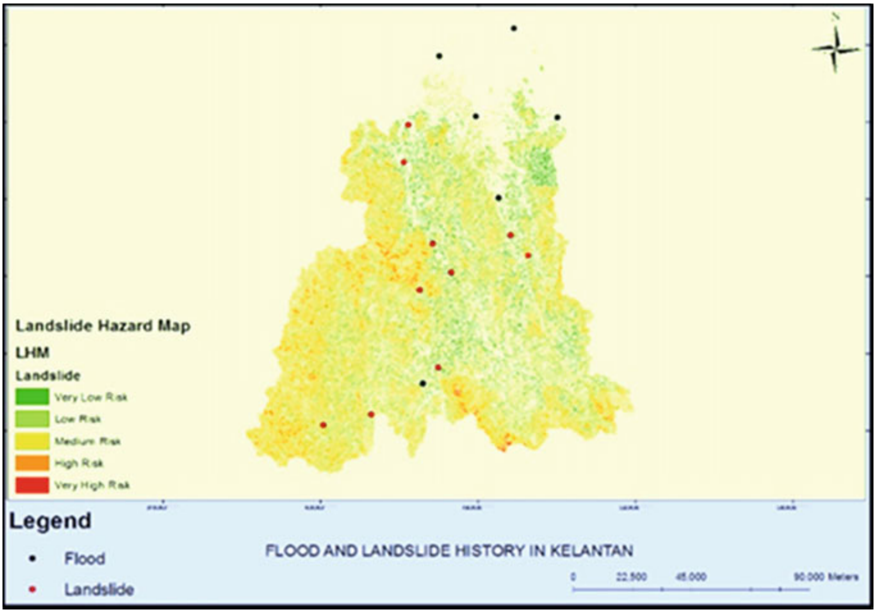


Fig.8 Landslide and flood historical map

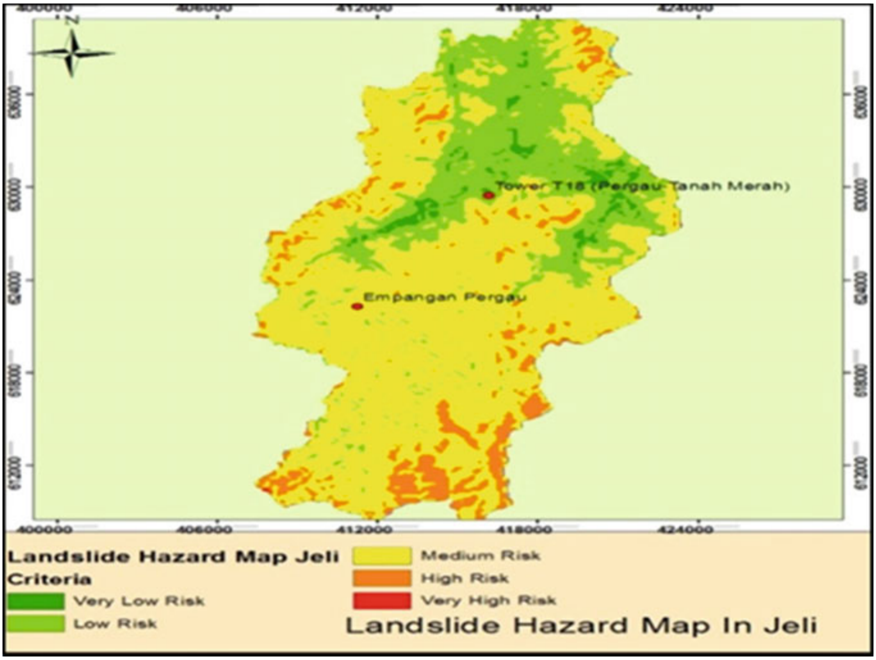


Fig.9 Jeli landslide potential risk map

Landslide Risk ranges from very low risk to very high risk. Jeli Landslide Hazard Map and risk condition can be used in local plan or geohazard strategies risk plan and planning permission brief or geohazard risk evaluation as described in Table 2. However, classification of the development criteria to be used for permission brief or zoning map are categorized based on the environmentally sensitive area and sensitive geological area [8–14]. Integrating information from Fig. 7 and Fig. 8 shows that the site of Jeli was categorized as:

a. Development category of Areas of Controlled Development: associated with Insensible

and Slightly Sensitive terrain or Class I and Class II terrain.

b. Development of Non-or Minimize development: associated with Sensitive and Highly

Sensitive terrain or Class III and Class IV. Special guidance and administration required for the development of these terrains.

c. Development can enhance socio-economic activities such as agriculture, quarry

aggregates, and sand mining. Developments to improve socio-economic conditions should be carried out and monitored once they are in operation

Development category was divided based on the zoning concepts described in Act 172 and Fig. 9. Jeli areas were categorized into three zones, namely restricted development zone, buffer zone, and conservation zone. The information translated from the thematic maps (Fig. 9) is briefly described in Table 3. Zone 1 is the area with an insensitive and slightly sensitive range from very low risk to low risk, considered as a restricted development zone. This zone can be developed from moderate to high intensity but needs to be regulated because these areas were considered as the area that can enhance the socio-economic. Zone 1 represents the area indicated as very low risk to low risk as shown in Fig. 9. Zone 2 is represented by medium risk area category as areas of controlled development (Fig. 9). Zone 2 is allowed to have intensity development from moderate to high with a buffer zone to prevent this zone from geohazard. Zone 3 is considered as moderate risk represent by high-risk area, as shown in Fig. 9. The development needs to minimize with a buffer zone, and part of the site needs to be reserved. Zone 4 is a restricted high-risk area, which cannot be developed and considered as a conservation area. Figure 9 shows a very high risk, represented by Zone 4.

1.6 Managing Development on Zone 2 and Zone 3

Specialized Investigation and mitigation procedure as shown in Fig. 4, was extended by integrating geoscience information in order to comply with guidelines of development as tabulated in Table 3. Specialized investigation and mitigation procedure as shown in Fig. 10, was formulated based on the integration of site investigation for

Table 3 Zoning based on Jeli landslide risk map [11, 13, 16]

Malaysia physical planning process			
Land suitability Restriction	Development Risk	Guideline of development	Development intensity
CLASS I *Insensitive* *Very low risk- Low risk*	Lower risk (low site investigation cost)	Areas of controlled development and development, which can enhance the socio-economic (Restricted development zone)	Intensity from moderate to high
CLASS II *Slightly sensitive medium Risk*	Slightly moderate risk (high site investigation cost)	Areas of controlled development (Restricted development zone and Buffer Zone)	Intensity from moderate to high
CLASS III *Sensitive* *High risk*	Moderate Risk (high site investigation cost)	Development of non-or minimize development (Buffer and conservation zone)	Intensity from moderate to high
CLASS IV *Highly sensitive* *Very high risk*	Highly Risk (extreme site investiga-tion costs)	Development of Non-or Minimize development (Conservation zone)	Intensity low (Green area, recreational area)

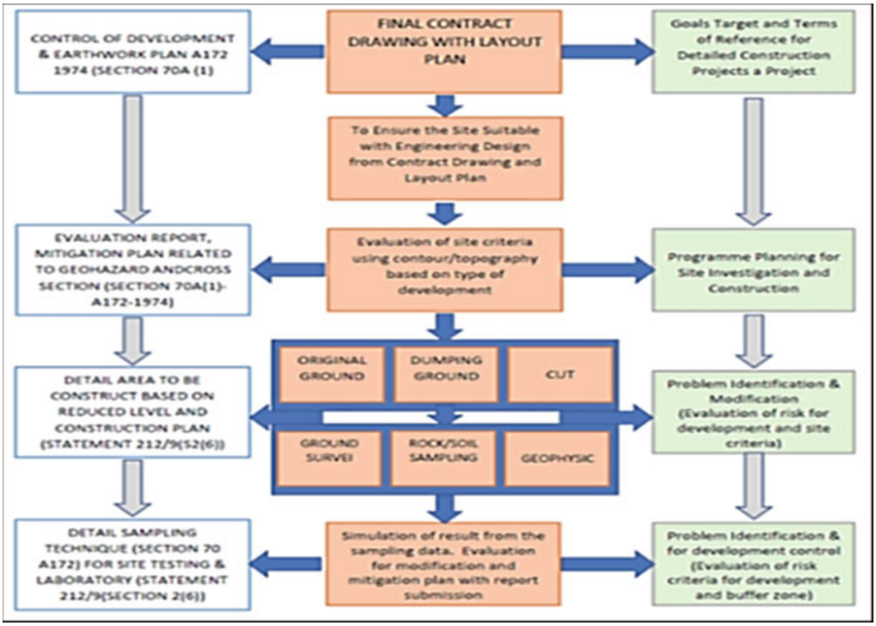


Fig. 10 Specialized investigation and mitigation procedure

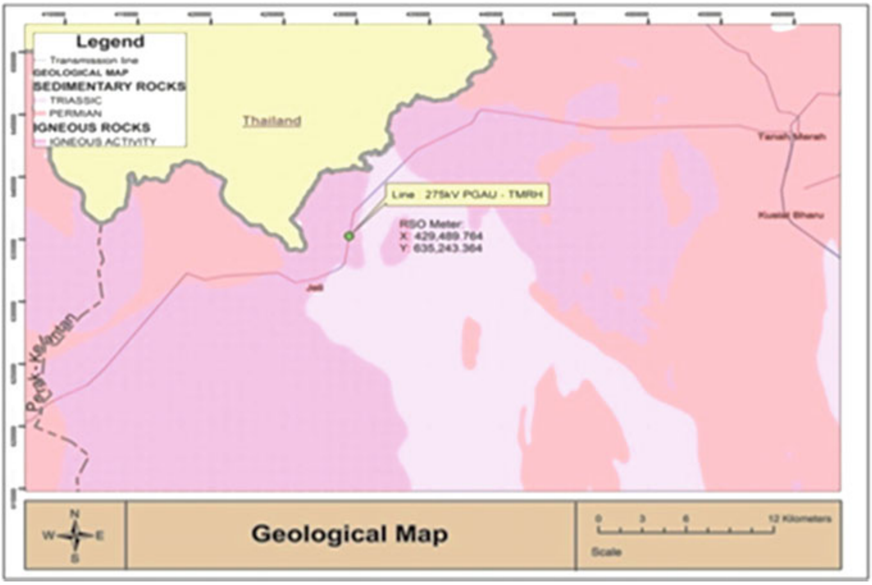


Fig.11 Study area and location of T18 [21]

construction and engineering design with policy named as, the control of development related to earthwork as mentioned in Sect. 70A (1) in A172 1974, Sect. 2(1) and details from a statement in 212/91 (Sect. 2(6)), 212/91 (Sect. 2(8)), 212/91 (Sect. 2(9)) and P.W.5178/85 [3]. Data analysis from satellite imagery and combination of spatial data from the geological map, land-use map, and topography map were used to interpret the best location for geophysics mapping [15–18]. Integration data from geological map, land-use map, and topography map were translated as surface geology map (Fig. 11) and geological cross-section (Fig. 12). Cross-section map is used as a guide to locate the non-destructive test and borehole drilling to get the information on the condition of the site to be developed.

At T18 site, a 200-m length of two lines resistivity survey was performed as shown in Fig. 13. The survey revealed that the subsurface consisted of sandy soil from weathered phyllite above the groundwater level, ranging from 251–260 Ω-m. From the resistivity test, the groundwater was located 10.0 m from the ground level. A 5.0 m × 10.0 m grade III boulders weathered phyllite was detected above the groundwater level with resistivity ranging from 2771 to 3390 Ω-m as shown in Fig. 13. This area consisted of entirely weathered rock with RQD values of 25 to 50%, and a quarter of the site has RQD values of 50 to 75%. A firm to very stiff sandy clay soil with SPT-N values from 7 to 29 was discovered below the groundwater level [21].

The discontinuity survey was conducted at T18 because the scars indicated that the area has a historic landslide [21]. To provide a back analysis of the slope stability prediction, a total of 100 discontinuity data was collected during the discontinuity

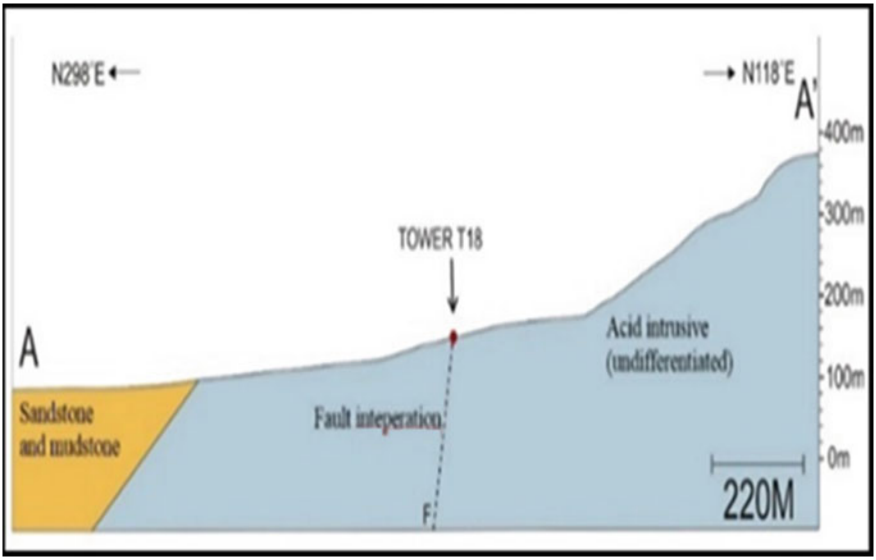


Fig. 12 Cross-section of T18 [21]

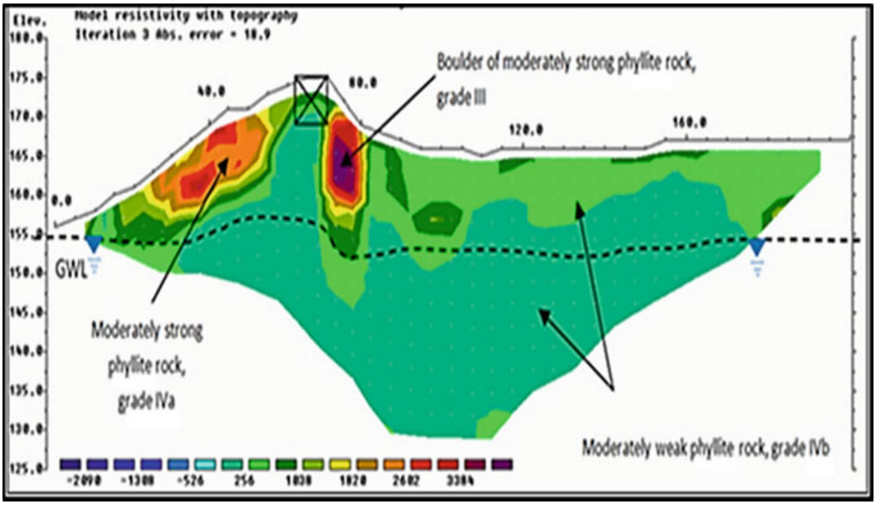


Fig.13 Resistivity profile at T18 Cross-section [21]

survey (Fig. 14) and kinematic analysis was carried out to predict the slope stability at T18 as shown in Fig. 15. The slope face has five-pole discontinuities marked as D1, D2, D3, D4, and D5, the highest concentration followed by others. The orientations of these poles are D1 = N312/E/47/E, D2 = N129/E/50/E, D3 = N162/E/21/E, D4 = N230/E/53/E and D5 = N236/E/29/E. Using 30° as an internal friction angle from

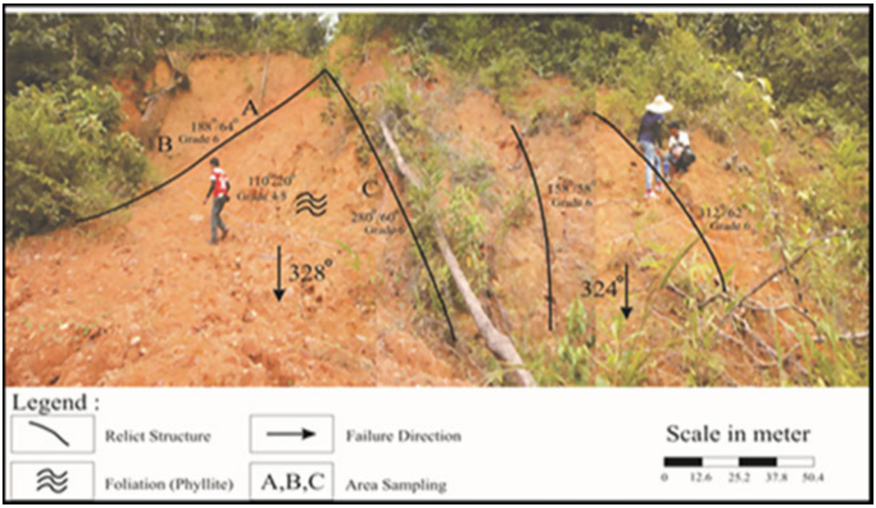


Fig.14 Discontinuity mapping and in-situ sampling at T18 [21]

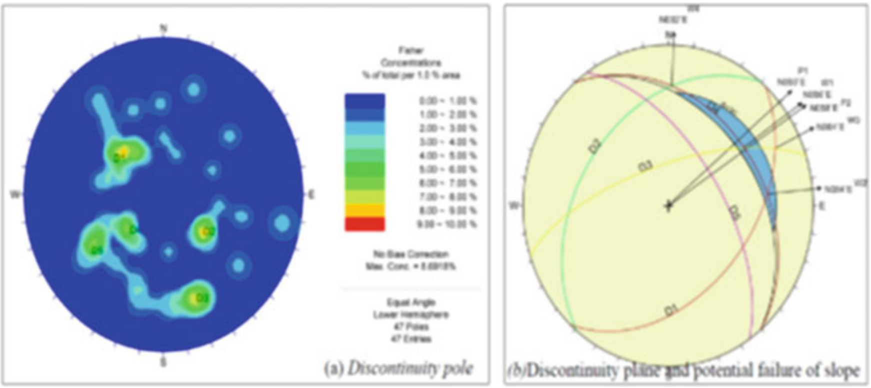


Fig.15 Kinematic analysis at T18 [21]

universal internal rock friction angle, this site's slope inclination strikes N320E with a dip of around 40o. Four possible failures are classified as P1, P2, W1, and W2, as shown in Fig. 15.

Thirty-six (36) in-situ samples from grade V and grade VI soils were obtained from T18 as shown in Fig. 14 for triaxial consolidated drained testing using the proposed technique shown in Fig. 16. The collection of sample-based on the direction of discontinuity data (Fig. 16) and results from the triaxial consolidated drained test were analyzed to predict the stability of the slope at the study area and to identify the cause of failure. Figure 17 shows the slope stability analysis by SLOPE/W, and the factor of safety value is 0.627, which is less than 1 (modification from [21]). Analysis

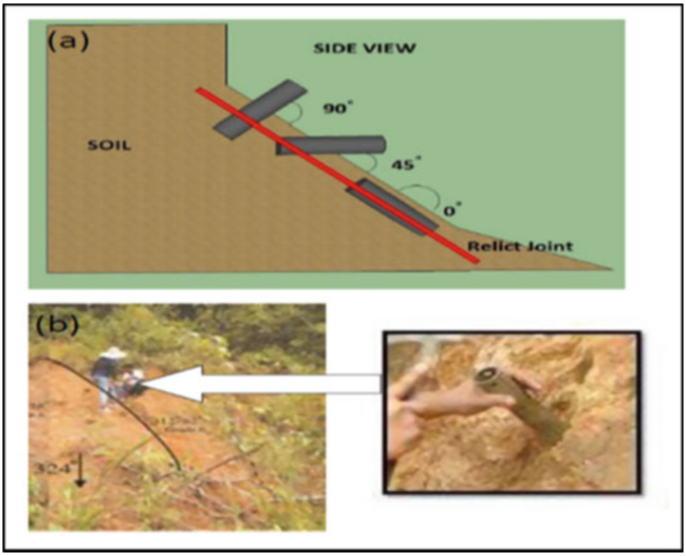
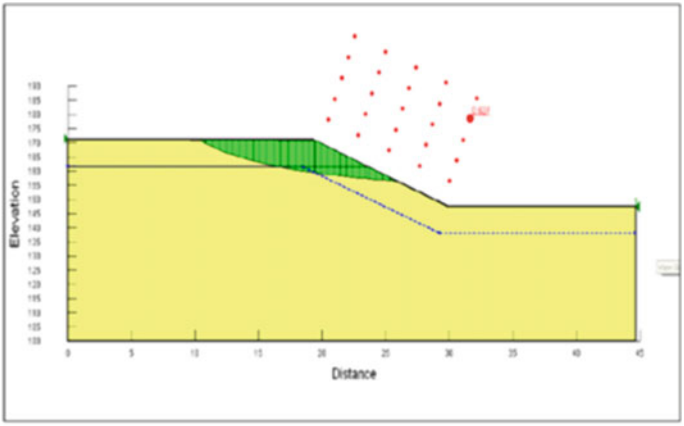


Fig. 16 Proposed sampling technique at T18 [21]



No.	Type of soil	Note	Unit weight	Cohesion	Friction angle
1.	Sandy SILT	Above ground water level	16.00 kN/m³	6.0 kN/m²	20°
2.	Saturated Sandy CLAY	Below ground water level	19.00 kN/m³	10.0 kN/m²	18°

Fig. 17 Results of slope stability analysis at T18 [21]

using kinematic technique and slope stability of the landslide zone sample revealed the presence region failure or weak zone caused by discontinuity and weathering cycle as tested earlier based on the geology cross-section, kinematic analysis, slope stability analysis, RQD values 50% to 75%, and SPT-N values from 7 to 29. It also can be shown clearly in a terrain map, indicated as 2C3b (Fig. 7) which was prone to erosion and landslide zone in between 10 to 50 m near the natural stream.

1.7 Conclusion

Developing an integrated site investigation protocol would be best for assessing landslide danger for land suitability restriction, particularly for Zone 2 and 3. The process requires an integrated approach in collecting geoscience information to make the optimal usage of resources while mitigating geohazards for construction risks in order to determine the optimum cost strategy for site analysis, not only for the short term but also for the future. It should also ensure that priorities, regulations, and management approaches regarding natural disaster reduction are integrated into the physical land-use plan. The structural plan with geohazard information encourages local land-use decisions to consider the risks posed by natural hazards. Additionally, by considering hazardous conditions in the land suitability analysis, the zoning plan can concentrate on the development and infrastructure expansion in those areas with lower risk.

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