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Climate Action

Suraj Mal
R.B. Singh
Christian Huggel *Editors*

Climate Change, Extreme Events and Disaster Risk Reduction

Towards Sustainable Development Goals

Springer

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Foreword

Climate Change, Extreme Events, and Disaster Risk Reduction is a timely publication in view of the threats the world is facing today due to climate change and related extreme events and the well-coordinated counterefforts against them, such as Sendai Framework for Disaster Risk Reduction (SFDRR) 2015–2030.

Global climate change is well-established now, as revealed by such international organizations as ICSU, IPCC, and WMO. It has led to the occurrence of many types of extreme events across the world, most important being hydrological and climatic ones. These extreme events have further posed varying levels of threats to lives and livelihoods at global, regional, and local levels. They require multi-level planning linking international agencies such as United Nations and national and local level bodies for disaster risk reduction.

In fact, the quest for disaster risk reduction started way back in 1989, when UN declared the 1990s as the International Decade for Natural Disaster Reduction (IDNDR). The efforts were further taken at international level in 1999 with the establishment of International Strategy for Disaster Reduction (ISDR). The program was adopted by UN and thereafter called UNISDR.

This book is a valuable contribution to the United Nations Sustainable Development Goal (SDG) of Climate Action as well as UNISDR and SFDRR. It contains 20 chapters covering a range of extreme events including hydrological and climatological ones, and their coping mechanisms and strategies across the world. It consists of two sections, viz. 1) Evidence of Climate Change and Extreme Events, and 2) Coping with Extreme Events and Disasters, comprising most relevant case studies from different regional and ecological settings.

Therefore, this book is highly recommended to policy makers, academics, researchers, and disaster managers for enhancing their understanding in the linkages between climate change, their impacts, and risk reduction.

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Preface

The Earth's climate has experienced an accelerated warming of 0.85 °C during the last century, which has resulted in modification of ecosystem processes and occurrences of many extreme events across the globe, including extreme temperatures (cold and hot weather) and rainfall (floods and droughts). Glacial lake out-burst flood events have become quite common in many vulnerable ecosystems such as mountain, coastal, and developing regions of the world. Besides these extreme events, long-term climate change is influencing worldwide glacier recession, sea-level rise, modifications to river regimes, soil erosion and sediment deposition, a reduction in agricultural yield, food security, and vegetation patterns and greenness, etc. These are among the major and visible changes. The level of income, education, health facilities, etc., have further contributed to the vulnerability of poor and developing nations to these extreme events, which have often led to significant damage to local economies, infrastructures, and populations. About 12,000 natural disasters were reported during 1970–2014 across the world (UN-ESCAP 2015), of which hydro-climatic disasters (floods and storms) represent the greater share. Though losses per disaster have declined over the years, due to marginally improved preparedness, coping mechanisms, and disaster responses, an increasing number of disasters have further exposed large populations in less developed countries. More than 1.6 million people have died due to disasters during 1990–2013, of which more than 95% of deaths occurred in developing countries (UNISDR, 2015; IPCC, 2012).

Therefore, in order to cope with extreme events and reduce associated damage, many steps have been taken at the international level, which are well coordinated by the United Nations, etc. The International Decade for Natural Disaster Reduction (IDNDR) (1990–1999) was one of the first international initiatives, which was further developed to form the International Strategy for Disaster Reduction (ISDR) in 1999. The ISDR was adopted by the UN and subsequently called UNISDR. There have been three landmark international conferences dealing with disasters, namely: the 1st World Conference on Natural Disaster Reduction at Yokohama in 1994; the 2nd World Conference on Disaster Reduction at Hyogo in 2005; and the 3rd International Conference on Disaster Risk Reduction (DRR) at Sendai in 2015, which adopted three international landmark frameworks including the Yokohama Strategy (1994), the Hyogo Framework for Action (2005), and the Sendai Framework

(2015), respectively. Besides these, 2015 is considered as one of the most important years for DRR because three important initiatives were taken up during this year, namely, the Sendai Framework, the Sustainable Development Goals, and the Paris Climate Agreement (Poterie and Baudoin 2015; Kelman 2015).

This book focuses on the above stated international efforts as well as considering local case studies. The book contains two parts: Evidence of Climate Change and Extreme Events; and Coping with Extreme Events and Disasters. Chapter 1 summarizes the most important international initiatives, followed by 10 case studies dealing with evidence of climate change and extreme events. Part II contains 9 case studies focusing on coping mechanisms and disaster response. Therefore, the book represents a contribution towards the UN's Sustainable Development Goals and the Sendai Framework of DRR. The book is additionally useful for those involved in DRR research as well as policy makers—such as disaster management authorities, etc.

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Introducing Linkages Between Climate Change, Extreme Events, and Disaster Risk Reduction

Suraj Mal, R.B. Singh, Christian Huggel and Aakriti Grover

Abstract

Climate change has become an important factor for many environmental disasters in vulnerable communities and ecosystems. Poverty, poor education and health facilities and other aspects of human population in low and middle income countries have led to increased exposure and high levels of vulnerability and risk. Most of the deaths caused due to different disasters have occurred in developing countries. As a consequence, major efforts at the international level have been made to reduce the risks related to various disasters. The International Decade for Natural Disaster Reduction (1990–1999) was one of the important international initiatives followed by the International strategy for Disaster Reduction (1999), the Yokohama Strategy (1994), the Hyogo Framework for Action (2005), and most recently the Sendai Framework, the Paris Agreement, and the Sustainable Development Goals (all in 2015). Furthermore, the Intergovernmental Panel on Climate Change (IPCC) has played a fundamental role in assessing the state of knowledge in climate and impact science for almost 30 years. This introductory chapter summarizes the international initiatives in this field and thus prepares the ground for the following chapters which are introduced at the end of this chapter.

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Introduction

The Earth's climate has experienced unprecedented warming over the past few decades(IPCC 2012). The average global surface temperature has risen by 0.85 °C during the period of 1880–2012, and the last three decades (1983–2012) were the warmest 30 years over the last 1400 years in the northern hemisphere (IPCC 2013). As per climate model results, the global surface temperature is expected to further rise by 1–4 °C on the average by the end of this century relative to the period of 1986–2005, strongly depending on the greenhouse gas emission pathways (IPCC 2012). The changes in the climate systems have aggravated modifications in functioning of ecosystems (Schickhoff et al. 2016; Shrestha et al. 2012; Xu et al. 2009) and led to occurrence of many extreme events across the globe (IPCC 2014a, b; Vargas et al. 2017; Sorokin 2017). The frequency of high temperature events, warm days, and nights has increased, while low temperature events, cold days, and nights have declined across the globe (IPCC 2013). Extreme rainfall events (floods and droughts) have increased in many parts of the world (Goswami et al. 2006; IPCC 2013, 2014a, b; Schickhoff et al. 2016), while the number of rainy days has declined (Rani and Sreekesh 2017).

The model results suggest that due to future climatic warming, related extreme events will increase during this century. High temperature events are expected to increase, whereas the number of cold days and nights will decline (IPCC 2013). The frequency of heavy rainfall events is expected to increase, as well as wildfires due to increased evaporation, transpiration, and drought spells in future (IPCC 2012, 2013). As a result of temperature increase sea level will rise, which may at a later stage lead to global cooling as well (Sorokin and Mondello 2017). Besides extreme climate events, the major impacts of the climate change include changes in the microclimate and weather patterns (Praveen and Sreekesh 2017; Rani and Sreekesh 2017; Sorokin 2017; Degórska and Degórski 2017), worldwide glacier recessions (Bolch et al. 2012) and associated sea level rise (IPCC 2012) and coastal flooding (Chen et al. 2017), sedimentation in river basins (Ahmad and Das 2017), glacial lake outburst floods (Allen et al. 2016; Quincey et al. 2005; Huggel et al. 2002), changes in the vegetation patterns (Zolotov et al. 2017) and phenology (Kundu et al. 2017), agricultural yield (Milanova et al. 2017; Schick et al. 2017), food security (Beer 2017), and damage and loss to populations and economies (UNISDR 2008; Singh 2006; Mukwada and Manatsa 2017).

State of Disaster Impacts: Emerging Scenario

According to a UN-ESCAP Report (2015), a total of 11,985 natural disaster events were reported in the world during 1970–2014, of which floods and storms share about 64% and represent sharp increasing numbers in recent decades. However, the magnitude of changes in climatic extremes is not uniform across the globe, wherein some vulnerable ecosystems such as high altitude (mountains), high latitude, coastal regions, and developing regions such as Asia have observed more visible changes (IPCC 2014a, b; CRED-UNISDR 2015; Shrestha et al. 2012; Xu et al. 2009). The climatic extremes have repeatedly resulted in major disasters including heavy losses of infrastructure, economy, natural environment, and human populations (IPCC 2012), not only in the immediate areas but also affected downstream regions (Bisht et al. 2011; Evans and Clague 1994; Mal and Singh 2014). For instance, the Uttarakhand floods (2012, 2013), the Mumbai floods (2005), and the Kashmir floods (2014) in India, the heat waves of 2003 and 2006 in Europe, in 2017 in Delhi, the extreme winters of 2009–2010 in Mongolia, the European floods (2013), and many other such events caused unparalleled damage (IPCC 2012). Additionally, the droughts, heat, and cold waves and other extreme events do not only affect the human population but also ecosystems which in turn may result in negative effects on people due to shrinking provisions of ecosystem services (UNIDR 2009). These extreme events over the period of time have further exposed large populations to different levels of risks, especially in developing countries making them highly vulnerable to disasters (Singh 2000, 2006; UNISDR 2008). In some critical regions such as the Himalaya, hydro-climatic extreme events have been observed to increase over the past decades (Stäubli et al. 2017; Joshi and Kumar 2006; Goswami et al. 2006) with often major consequences for the vulnerable population and local economy.

Developing countries and poor people in high-income countries are disproportionately affected, mostly due to lower level of preparedness, high degree of exposure, and vulnerability (UNISDR 2008, 2009, 2015a; IPCC 2014a, b; Poterie and Baudoin 2015). Increasing economic and social inequalities, high population growth, and haphazard unplanned developmental activities, especially in developing countries, have further negatively influenced adaptive capacity and coping mechanisms of local peoples (UNISDR 2008, 2009). The economically and socially weaker sections in developing countries are specifically at higher risk (Poterie and Baudoin 2015). Significant economic inequalities can be understood from the fact that the lowermost half of the global population owns less than 1% of total global wealth (UNISDR 2015a).

According to the UN Global Assessment Report on Disaster Risk Reduction , more than 1.6 million people died due to different disasters worldwide during 1990–2013 (UNISDR 2015a), with more than 95% of the deaths worldwide during 1970–2008 from natural disasters occurred in developing countries (IPCC 2012). The economic losses from such disasters have been estimated to be about US$ 250 billion to US$ 300 billion/year since 1990s, and expected annual economic losses by 2030 are estimated at US$ 415 billion, of which US$ 314 billion will be only in built environment alone (UNISDR 2015a). Further, the mortality and loss of economies due to disasters are increasing in low-income countries (UNISDR 2015a; UNESCAP 2015). Therefore, in view of the fact that climate change and related extreme events will lead to increased future losses (IPCC 2012; UNISDR 2015a), it is imperative to combat climate-related disasters and reduce the inherent risks toward a safer world in a coordinated manner at international, regional, national, and local levels.

Contribution of Intergovernmental Panel on Climate Change (IPCC): A Climate Watch

The IPCC has been the most important scientific organization working since the late 1980s in the field of and at the interface of international climate science and policy. The IPCC so far published five assessments reports and several special reports dealing with the scientific basis, impacts, adaptation, vulnerability, and mitigation of climate change. Among the major special reports "Managing the risk of extreme events and disasters to advance climate change adaptation," popularly known as SREX 2012, is the most important contribution in the field of climate-related disasters in recent times. Specifically, the SREX 2012 deals with climate change and related extreme events, their impacts and mitigation strategies at international to local levels.

The review of the various assessments and special reports indicates that the scientific understanding of extreme events and related disasters has over the period evolved from the technical understandings of the climate science and its impacts in First Assessment Report, introduction of mitigation and adaptation in Second Assessment Report, vulnerability in the Third and Fourth Assessment Reports, and eventually a strong focus on the risk component in the Fifth Assessment Report. According to IPCC (2012, i.e., SREX 2012), DRR focuses on minimizing the exposure and vulnerability and enhancing resilience against the climatic extreme events. The SREX was instrumental in bringing together the disaster risk and the climate change communities, and an important result was the agreement on a comprehensive definition of disaster risk involving probability of hazard, and degree of exposure and vulnerability (IPCC 2012).

The Fifth Assessment Report of the IPCC (2014a, b) demonstrated the important nexus between climate change mitigation, risks, and adaptation. Mitigation has a decisive role in effectively limiting climate-related risks, in line with Article 2 of the UNFCCC, while adaptation is important to reduce risks to lower levels. This nexus implies that less effective climate change mitigation implies higher investments in adaptation to reduce risks to tolerable levels.

The exposure and vulnerability to disaster are ever changing with time and space and largely depend on socio-cultural-economic conditions of communities and environmental factors. The level of education, economic status, class hierarchy, age–sex structure, geographic location, etc., determine the level of vulnerability and exposure to disasters (Singh 2015; IPCC 2012, 2014a, b; Grover and Parthasarthy 2012), which further determines the extent of impact of climate change and extreme events (Mirand et al. 2017). Thus, it is important to take them into account for the DRR and strengthening of local adaptive capacities to counterforce the increasing levels of disaster risks due to the widely observed increasing exposure and vulnerability (IPCC 2012; UNISDR 2010).

Changing Perceptions of Disaster Risk Reduction

The mitigation of disasters is attempted through the disaster management cycle that has primarily three stages, namely, pre-, during, and post-disasters. Disaster mitigation, preparedness, relief, rehabilitation, risk reduction, and response are important components of disaster management cycle. Overtime, the stage to be focused has shifted depending upon the understanding of the concept of disasters.

The concept and idea of DRR and related notions have evolved over the years expending (Fig. 1) its horizon from disaster reduction in the early 1990s to coping capacities and relief interventions (response and recovery) in the early 2000s to risk reduction, preparedness, prevention, management, and adaptation to climate change by reducing the vulnerability and building resilience, involving more socio-economic-institutional components in recent times (Poterie and Baudoin 2015; Brieceno 2015a, b).

The discourse related to disasters at the international level began in 1989, when the United Nations declared 1990–1999 as the International Decade for Natural Disaster Reduction (IDNDR) in view of the increasing extreme events caused due to climatic and anthropogenic changes (Poterie and Baudoin 2015). Here, the focus was only on natural disasters. The IDNDR primarily focused on the reduction and prevention of the disasters itself, e.g., flood extents and associated damages were attempted to be reduced based on structural measures such as check dams, embankments, and other technological interventions. Research on disasters during the IDNDR therefore often had a more technological perspective and had limited focus on reduction of risks and exposure as important components and drivers of risk, and key aspects for managing disaster risk.[1,2]

The First World Conference on Natural Disaster Reduction held in Yokohama in 1994 adopted the landmark "Yokohama Strategy" and "Plan of Action for a Safer World: Guidelines for Natural Disaster Prevention, Preparedness and Mitigation," which reasserted the IDNDR's focus (Poterie and Baudoin 2015). It urged upon

[1]http://www.unisdr.org/who-we-are/international-strategy-for-disaster-reduction. Accessed on June 1, 2017.

[2]http://www.eird.org/eng/revista/No15_99/pagina2.htm. Accessed on June 1, 2017.

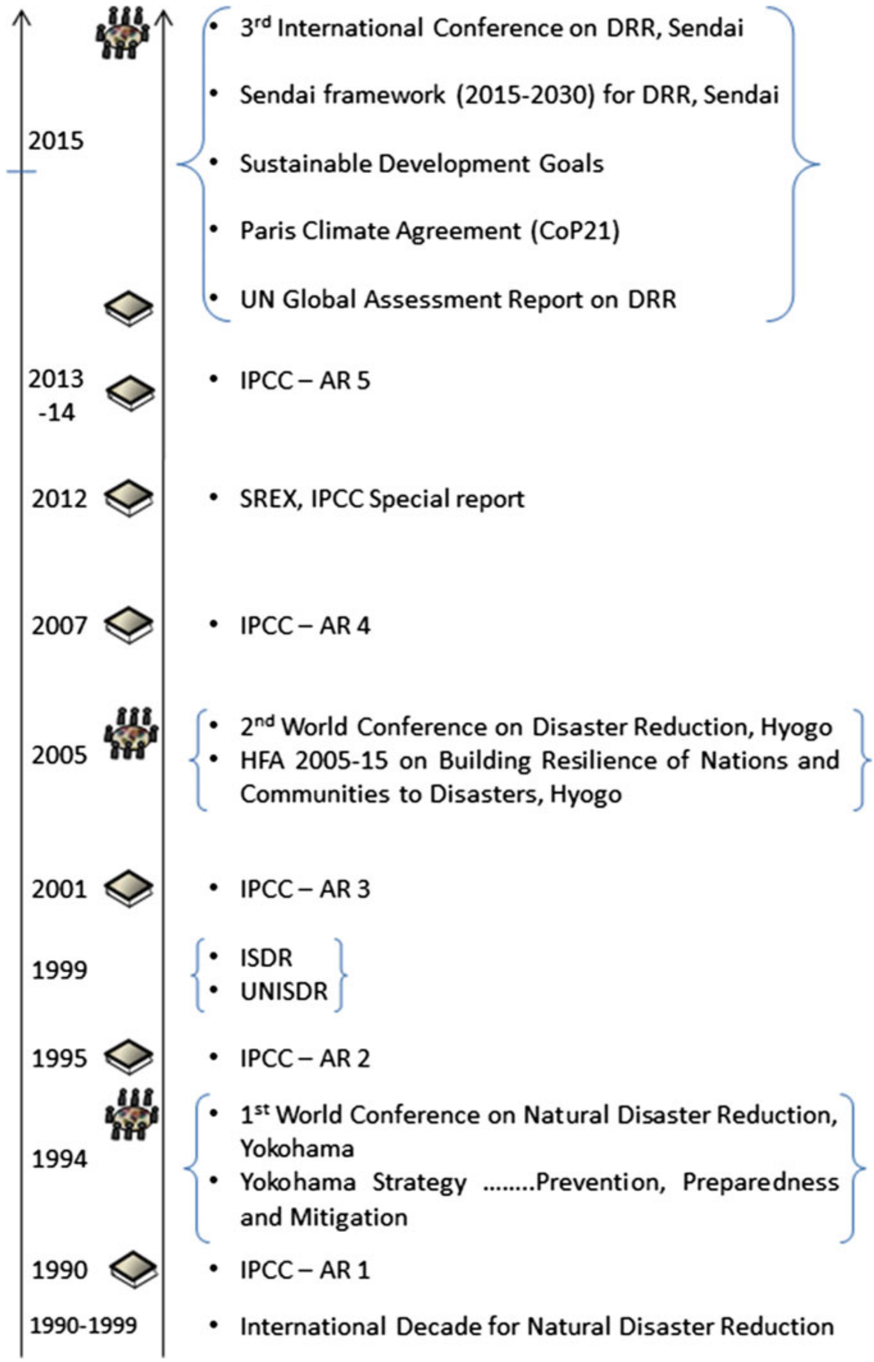

Fig. 1 Development of concept of DRR during last three decades

disaster prevention, preparedness, early warning, recovery, enhancement of local capacities, improvement in coping mechanisms, and integration into national policies to reduce the impact of disasters (UN 1994a, b). The recognition of traditional knowledge, practices, and values in addition to the local expertise was among the prime focus of the strategy (UN 1994a).

Later in 1999, the international efforts were further strengthened by launching the International Strategy for Disaster Reduction (ISDR). The ISDR was based on the experiences and lessons learned during the IDNDR (1990–1999) that the hazards and disasters are unavoidable and will affect the human society in future (see Footnote 1 and 2). Besides, there were some shortcomings and gaps that could not be properly considered during the IDNDR, which were also stressed upon in the Yokohama Strategy (1994). The report of 2nd World Conference on Disaster Reduction (2005a) underlined some major gaps in the Yokohama Strategy (1994) including "(1) disaster governance and policy framework, (2) identification of risk and its assessments and monitoring, (3) management of knowledge and disaster education, (4) preparedness for effective response and recover system, and (5) improvement in national and local capacities to build their resilience to ensure disaster risk reduction and sustainable development" (UNISDR 2005a, b).

Therefore, the prime focus of ISDR was to reduce the risks associated with the hazards and disasters. The scientific learning, the societal knowledge, and indigenous cultural practices were increasingly recognized to minimize and prevent the disasters (see Footnote 1 and 2). The broad vision of ISDR was to make human society more resilient to the hazards and risks by reducing their vulnerability to disasters (Poterie and Baudoin 2015). The ISDR further called for the integration of risk prevention strategies through involvement of authorities and local communities into the practice of sustainable development (see Footnote 1 and 2).

The ISDR program was adopted by the UN in 1999 and thereafter called United Nation International Strategy for Disaster Reduction (UNISDR). The UNISDR is responsible for the implementation of DRR programs and strategies among the UN member countries. The discussions at the 2nd World Conference on Disaster Reduction (2005) in Hyogo, Japan, further expanded the scope of DRR by involving the resilience component of communities to disasters. The conference adopted the "Hyogo Framework for Action (HFA) 2005–2015: Building the Resilience of Nations and Communities to Disasters," which was perhaps the most important document that popularized the DRR notion across the world (Poterie and Baudoin, 2015).

The main aim of the HFA 2005–2015 was to reduce disaster-induced losses of population, socio-economic, and environmental assets (Poterie and Baudoin 2015) by promoting an active role of local learning, resilience building, and climate adaptation through the integration of DRR into strategies and the planning process by 2015 (UNISDR 2005a, 2008). Therefore, five key areas of priority were identified, viz. (1) DRR as a priority in national policy, (2) identify, assess, and monitor disaster risk and enhance early warning, (3) use knowledge, innovation, and education to build a culture of safety and resilience at all levels, (4) reduce the underlying risk factors, and (5) strengthen disaster preparedness for effective response at all levels (UNISDR 2005a, b). However, community learning and experiences were not well recognized and promoted. The HFA 2005–2015 increased the focus on risk preparedness, prevention, and reduction of risk vulnerability in lieu of response and recover as stressed during the ISDR (Poterie and Baudoin 2015).

The year of 2015 was perhaps the most significant year in the discourse of DRR and international frameworks for sustainable development, since three important events, viz. the Sendai Framework for DRR 2015–2030 and the Sustainable Development Goals, both voluntary, and the legally binding treaty of the UNFCCC, i.e., Paris Agreement (CoP-21) took place this year (Poterie and Baudoin 2015; Kelman 2015).

The Sendai Framework for DRR 2015–2030, the successor of HFA: 2005–2015 (Poterie and Baudoin 2015; Kelman 2015), was discussed and adopted at the third International Conference on DRR at Sendai, Japan, in 2015 (UNISDR 2015b; Briceno 2015b). Over the period of nearly three decades, on account of global initiatives, the average number of disaster-related mortality (deaths per disaster) has slightly declined since 1970 (UNESCAP 2015). In many cases, it is observed that the hazards and extreme events are not necessarily leading to disasters (Kelman and Glantz 2015) as they are managed well through better coordination of early warning systems, preparedness, and disaster response. However, the number of affected people continued to rise over last 10 years, leaving over 1.4 million people injured and about 23 million homeless (UNISDR 2015b). Besides, the exposure and vulnerability levels of poor and dependent sections, especially in the developing countries have increased (Briceno 2015a). The Sendai Framework 2015–2030 witnessed a paradigm shift from HFA: 2005–2015, wherein the thrust now shifted to adaptation to climate change, increased resilience to present and future hazards, and management and mitigation of disaster risk (Poterie and Baudoin 2015). In addition to the natural hazards, the Sendai Framework focused on the human-made hazards, and risks related to techno-environment and biological hazards (UNISDR 2015b). Earlier, the disasters were considered purely natural phenomena, but by 2012 it was recognized that significant causes of disasters are anthropogenic in nature (IPCC 2012), e.g., floods are not just natural hydrological events but can be indirectly caused by anthropogenic activities such as large-scale deforestation, resulting in changes in local climates, altered runoff regimes, and eventually floods.

It was also realized during 2005–2015 that DRR can be further improved through governance involving various stakeholders from local to global levels, building resilience of local communities, better preparedness, and response mechanisms (Singh 2015). Besides, DRR is required to be more people-centric with involvement of governments with vulnerable groups, viz. woman, youth, poor, person with disability (UNISDR 2015b). Further the trans-boundary cooperation, local capacity building, technology transfer, and financial support were needed for better DRR process (Kelman 2015).

The Sendai Framework also focused on prospective risk management, reducing existing risks and compensatory risk management (UNISDR 2015a, b), which are also stressed in the Global Assessment Report on DRR (UNISDR 2015a). Therefore, the Sendai Framework prioritizes four key areas for action, i.e., (1) understanding disaster risk, (2) strengthening disaster risk governance to manage disaster risk, (3) investing in disaster risk reduction for resilience, and (4) enhancing disaster preparedness for effective response and to "Build Back Better" in recovery, rehabilitation, and reconstruction (UNISDR 2015b). The fundamental aim of the Sendai Framework is to substantially reduce number of deaths and affected people, economic loss, infrastructure, and basic services by 2030 (Singh 2016; Poterie and Baudoin 2015). Besides, it also promotes the coordination and cooperation among its parties (member countries) for better DRR (UNISDR 2015a, b). DRR has now become an international strategy to spread awareness about causes, impacts, and reduction of impacts of disasters (Poterie and Baudoin 2015). However, Briceno (2015b) identifies some shortcomings in the Sendai Framework 2015–2030, viz. "prioritization in the implementation of recommendations of the Sendai Framework, quantified tasks, and implementation plan for the frameworks." There was more focus on science and technology and less on value of local knowledge, learning, and practices with respect to DRR (Poterie and Baudoin 2015). Kelman (2015) suggested that the "hazard part of disaster risk is overemphasized and to effectively combat DRR it could focus more on vulnerability and resilience to climate change." The DRR process was further strengthened through UNISDR Science and Technology Conference at Geneva during January 27–29, 2016. The conference focused on global partnerships, integrated linkages of exposure, vulnerability and risks, collection and use of data including the standards and innovative practices, knowledge hubs, gender inequality, supporting publishing practices, youth involvement, bioethics, and ethics of science and technology in DRR with active input from IAP (the Inter-academy Partnership)-Global Network of Science Academies (Dickinson and Murray 2016). IAP also organized General Assembly at Hermanus, South Africa with initiating a panel on science advice during emergency situations arising out of disasters. The DRR is further strengthened by constituting a working group of Experts on Science and Technology for DRR by IAP for bringing global issues to the attention of policy makers.

Emergence of SDGs for Global Sustainability

The Sustainable Development Goals (SDGs), also known as “Transforming our world: The 2030 Agenda for Sustainable Development” succeeded the Millennium Development Goals (MDGs). The MDGs indirectly aimed to confluence with the aims of the ISDR by eradication of poverty, education promotion, environmental stability etc[3]. The Sendai Framework and the SDGs were approved by the UN in 2015. The SDG framework is closely linked to and inherently supports DRR efforts. The SDGs can play an important role to develop resilience toward disaster exposure, vulnerability, and risk reduction (UN 2015). The UNISDR (2015a) asserts that “development cannot be sustainable unless the risk of disasters is reduced”. In total, 17 goals and 169 targets were identified with the broader objectives to end poverty, access to resources, lowering the inequalities, ecological balance with inter- and intra-generational equity, and combat climate change impacts (UN 2015). The SDGs closely align with DRR, which involves understanding the scientific bases of a variety of natural and socio-economic processes, capacity building of local authorities, communities, and other stakeholders for DRR.

The SDG 13, i.e., “Climate Action” particularly deals with international efforts to minimize the impacts of climate change by taking steps such as promotion of renewable energy and reduction of emission of greenhouse gases[4]. The SDG Climate Action was included in the SDGs with the view that climate change presently is one of the biggest challenges for our society. The SDG on climate action has identified some important targets to be fulfilled by 2030 that includes improving the understanding of disasters, enhancing the level of education, awareness, stakeholders and institutional capacity, adaptation, resilience, mitigation, risk reduction of hydro-climatic disasters across the world and integration of climate change into the national and local level policies (UN 2015).

The Paris Climate Agreement for Our Common Future

The Paris Agreement, product of and adopted at the Conference of Parties 21 (COP 21), the climate conference under the UN Framework Convention on Climate Change (UNFCCC), held at Paris in 2015, represents the historic and main international legally binding reference framework for climate change and related impacts (Rogelj et al. 2016). It thus essentially contributes to and is aligned with the SDGs. All the parties (countries) are committed to the common goal to (1) limit the increase of temperature to under +2 °C by and if at all possible to as low as +1.5 °C (as referred to pre-industrial conditions) by controlling greenhouse gas emissions[5] and (2) reaching the greenhouse gas emission peak as soon as possible, and (3) balance between anthropogenic greenhouse gas emission and removal by sinks in the second half of this century (UNFCCC 2015; Rogelj et al. 2016). Therefore, the course of development during this century is expected to be free of fossil fuels (Obergassel et al. 2016). It focuses on climate resilient development through adaptation of climate change complemented by suitable financial flows (UNFCCC 2015). As part of the policy, individual countries submitted their climate actions for post-2020 and are required to report the progress of emission cuts every five years to UNFCCC under the Intended Nationally

[3] http://www.unisdr.org/2005/mdgs-drr/link-mdg-drr.htm. Accessed on June 1, 2017.

[4] https://sustainabledevelopment.un.org/sdg13. Accessed on June 1, 2017.

[5] http://unfccc.int/resource/docs/2015/cop21/eng/l09r01.pdf. Accessed on June 1, 2017.

Determined Contribution policy (INDC) (UNFCCC 2015) (See Footnote 5)[6].

The Paris Agreement was crucial in view of the fact that major greenhouse gas emitting countries ratified this agreement[7]. So far, of the 197 member countries, 147 have ratified this agreement (see Footnote 6). As part of the agreement, the USA committed to reduce the greenhouse gas emissions by 26–28% from the 2005 levels and the European Union decided to cut the emissions by 40% by 2030 from the 1990 levels (see Footnote 7). However, the commitments in agreement face major challenges since limiting the temperature rise and greenhouse gas emissions to the suggested levels will require substantial efforts on part of the INDCs (Rogelj et al. 2016). Recently, the US government has decided to quit the agreement, representing a serious setback to climate change negotiations. Obergassel et al. (2016) suggest that even if the agreement is fully implemented, the average temperature will still increase by 2.7–3.5 °C. Sincere actions at national, sub-national, and non-state levels are required to meet the global targets agreed at the Paris Agreement (Rogelj et al. 2016).

Present Initiative

The complicated nature and dynamics of impact of disasters probes us for further investigations on microlevel studies and trying to explore the common thread for making policies at the global level. In this context, 19 case studies representing different ecosystems have been presented in two sections of the present volume, viz., (1) evidence of climate change and extreme events and (2) coping with extreme events and disasters, while the introductory Chap. 1 is attempted to explain inter-linkages of climate change, extreme events, and the development of concept of DRR, vulnerability, and hazards. The section on climate change and extreme events covers ten case studies from the study of weather- and climatic-related disasters in high mountains of the world including Hindu-Kush-Himalaya, Andes, European Alps, and mountains of Africa and central Asia, to impacts including vegetation changes, plants activities, food security, and urban environmental hazards induced from rainfall and temperature extremes (floods and droughts).

The Chap. "Analysis of weather- and climate-related disasters in mountain regions using different disaster databases" analyzes weather- and climatic-induced disasters in major mountains of the world. The study uses four disaster databases to analyze weather and climatic disasters in World Mountains. The mountains are globally fragile and are prone to variety of disasters. Though there is insufficient evidence to explain the increasing frequencies of mountain hazards and their linkage to climate change.

The Chap. "Influence of climate change on environmental hazards and human well-being in the urban areas—Warsaw case study versus general problems" assesses the impacts of changing urban landscape and their sensitivity to climate change which is further linked to quality of life. The changing climates of urban areas caused by land use changes have led to the formation of heat island, which has negative implications on the quality of human life. The changed land use patterns and associated changes in local climate will worsen the quality of life especially in case of vulnerable population such as elderly people and children.

The Chap. "Physiographic Influence on Rainfall Variability: A Case study of Upper Ganga Basin" deals with rainfall variability caused by physiographic factor in upper Ganga Basin, India. The study reveals that rainfall variability is high in the pre- and post-monsoon season, whereas monsoon rains show relatively stable rainfall in Ganga Basin. The annual rainfall trend shows no significant changes in study area.

The Chap. "Water Deficit Estimation under Climate Change and Irrigation Conditions in the Fergana Valley, Central Asia" discusses the

[6]http://unfccc.int/paris_agreement/items/9485.php. Accessed on June 1, 2017.

[7]https://www.weforum.org/agenda/2016/09/what-is-the-paris-agreement-on-climate-change/ Accessed on June 1, 2017.

changes in irrigation water deficiency in the Fergana valley of Central Asia under different climate scenarios for 2020, 2050, and 2080 based on future weather patterns developed from Global Circulation Models (GCM). The irrigation water demands are likely to increase in future due to increased Potential Evaporation (PET) caused by an increase in temperatures and changes in precipitation. Similarly, the area under irrigation water deficiency will increase.

Long-term vegetation activity responses to rainfall changes have been studied in Bundelkhand region in the chapter "Long-Term Trend of NDVI Response to Rainfall: A Geo-Spatial Approach." Varying patterns of vegetation trends to rainfall have been found in the study area. Temperature and rainfall variability for the upper Beas basin in western Himalaya were studied using Mann-Kendall and Sen's slope tests in seventh chapter. Significant warming trends and narrowing temperature ranges have been noticed in the study. The rainfall and rainy days have declined in the study area over a period of 1980–2010.

The impacts of extreme weather events on food security were explored in the Chap. "The Impact of Extreme Weather Events on Food Security." Extreme events directly damage agricultural land and hamper the food distribution chain system, especially in urban areas.

The changes in land use patterns of the land affected by sedimentation processes in Gumti River, Tripura, are analyzed in the Chap. "Sedimentation Induced Depositional Lands of the Gumti River of Tripura and its Land Use Pattern." Over the period of time, the sedimentation process in the banks of Gumti River has led to stable depositional land, where many land use/cover types (agricultural, vegetation, settlements, etc.) have emerged over the years.

Vegetation species activity changes as a result of anthropogenic transformations of landscape in Altai Krai are presented in the Chap. "Landscape Changes in the Activity of Higher Altitude Vascular Plants Species in the OB Plateau (Altai Krai, Russia)." As a result, the activity of steppe species decreased in zonal and intrazonal landscapes. The activities of many alien species have increased.

Shallow landslides as a result of rainfall have been attempted to predict in Uttarakhand Himalaya, India, in the Chap. "Application of Classification and Regression Trees for Spatial Prediction of Rainfall Induced Shallow Landslides in the Uttarakhand Area (India) Using GIS," based on Classification and Regression Trees (CART). A landslide inventory has resulted in the identification of 430 historic landslides. Eleven factors that may affect the landslide occurrence (slope angle, aspect, elevation, etc.) were used in the CART model. The results may be helpful in landslide impact reduction in the study area.

The second section of this volume deals with coping with extreme events and disaster case studies. A total of nine case studies are presented in this section, including topics such as droughts, flash floods, future global warming modeling and associated ocean expansion, El Niño, La Niña, and related economic losses to community resilience.

The recurrence of drought events and their impacts on the rural areas of Zimbabwe are analyzed in the Chap. "Is Climate Change the Nemesis of Rural Development?: An Analysis of Patterns and Trends of Zimbabwean Droughts?." Mean temperature and the severity of droughts increased in this study area. It led to losses in agricultural production, crop failures, food insecurity, and erosion of rural livelihoods and vulnerability of rural economies. The study urges for new resilience strategies in Zimbabwe.

The Chap. "Entering the new +2 °C Global Warming Age and a Threat of World Ocean Expansion for Sustainable Economic Development" deals with different temperature rise scenarios and likely sea level rise. It is assessed that if the global average temperature rises beyond 1.3 °C relative to pre-industrial level associated with 9.8 m sea level rise, it may destabilize the Earth's climate system and may further lead to global cooling. Therefore, the mid-century strategies for the transition to low-emission pathways should address this issue before it is too late.

Climate scenario and hydrological models were combined in a GIS environment to examine the rainstorm-led water logging impacts, river floods, and sea level rise in Shanghai, a coastal city in China in the Chap. "Climate change and coastal mega-cities: disaster risk assessment and responses in Shanghai City." Disaster risk assessment, prevention, and adaptation measures are explored along with suitable recommendations for spatial-specific emergency measures to enhance resilience in Shanghai.

Socio-economic impacts of hydro-climatic extreme events caused due to the La Niña event of 2010–2011 in Colombia are examined in the Chap. "La Niña event 2010–2011: hydroclimatic effects and socioeconomic impacts in Colombia." Flashfloods, landslides, and long-term inundations were caused by the La Niña event in 2010–11, which led to many socio-economic tensions. The communities were forced to leave their own regions and move to other regions, where many social conflicts worsened. Learning from this event may serve for strengthening the regional disaster risk management practices.

Taking the case study of Malaysia, the importance of artificial rains in rainfall deficit seasons is discussed in the Chap. "The Experience of Disaster Risk Reduction and Economic Losses Reduction in Malaysia during the Water Crisis 1998 in the Context of the Next El Niño Strongest on Record Maximum 2015." The impact and risk of drought can be effectively minimized through artificial rains during El Niño years.

DRR in mountain agriculture as a result of transformation from traditional agricultural practices to modern agroforestry practices are dealt with in the Chap. "Sustainable disaster risk reduction in mountain agriculture: Agroforestry experiences in Kaule, mid-hills of Nepal." Agroforestry was introduced with proper training of local farmers, which has positive impacts on soil quality and productivity, species richness and diversity, and livelihood security. It further has an impact on risk reduction in the mountain agriculture of Nepal.

The Magisterial community in the Valles urban area in San Luis Potosí, Mexico, has developed and adopted their own strategies to cope with flash floods (The chap. "Building Community Resilience to Flash Floods: Lessons Learnt from a case study in the Valles Urban Area, SLP, Mexico"). Although they are still not a resilient community, fundamental aspects for becoming the resilient community have been well developed.

Quantification of geo-diversity using topographic and climatological characteristics in Sikkim, India, has been done for conservation and DRR research (The Chap. "Quantification of Geodiversity of Sikkim (India) and its Implications for Conservation and Disaster Risk Reduction Research"). A geo-diversity map has been produced which roughly matches the biological richness map of Indian Institute of Remote Sensing (IIRS), India. The geo-diversity map can contribute to conservation of biological diversity in concerned regions.

Five different methods have been used to analyze peak water discharge for flood management in the Lower Gandak Basin, India, in the Chap. "Peak Discharge Analyses for Flood Management in Lower Gandak Basin." The floods are a curse for the people in the Gandak Basin and therefore, flood discharge estimation may contribute to reduction of the impacts of floods by initiating suitable engineering structures in the basin.

Conclusion

The concept of DRR has evolved over the years bringing new horizons based on continuous learning. Climate change-led extreme events have increased in past. In recent years, efforts in DRR also increasingly focused on the reduction of the vulnerability and exposure components, rather than looking mainly on the reduction of the hazard component of risk. Thus, the human components have been increasingly recognized as part of disaster risk reduction. The discourse of DRR is nearly three decade old, starting from IDNDR (1990s) to Paris Climate Agreement in 2015. Significant achievements in case of DRR have been made over the years; the average numbers of causalities per event have decreased.

However, still a lot remains to be done as the vulnerability and exposure to extreme events has also increased. Vulnerable sections of society are at particular risk including poor, disabled, dependent, un-educated, women, and therefore there is a need to focus on people-centric DRR in years to come.

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Part I

Evidence of Climate Change and Extreme Events

Analysis of Weather- and Climate-Related Disasters in Mountain Regions Using Different Disaster Databases

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Abstract

Mountains are fragile ecosystems with global importance, providing key ecosystems services within mountainous areas but also for the lowlands. However, mountain regions are prone to natural disasters and exposed to multiple hazards. In this chapter, we present four disaster databases (EM-DAT, NatCatSERVICE, DesInventar, Dartmouth) that store information about spatiotemporal occurrence and impacts of natural disasters in mountain areas. Quality and completeness of the four databases are compared and analyzed regarding reliability for weather- and climate-related natural disasters. The analysis identifies the numbers of fatalities as the most reliable loss parameters, whereby the number of people affected and the economic loss are less trustworthy and highly dependent on the purposes of each database. Main limitations regarding sustainable mountain development are the inhomogeneity in database definitions, spatial resolutions, database purposes and lack of data registration for human and economic losses. While some individual

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disasters such as the Kedarnath flood in northern India in 2013 have been robustly linked to changes in climate, there is generally insufficient evidence to attribute any overall increasing disaster frequency to climate change. Damage due to hazard in mountain regions will increase irrespective of global warming, in regions where populations are growing and infrastructure is developed at exposed locations.

Keywords
Disaster risk reduction (DRR) · Disaster databases · Weather- and climate-related disasters · Mountain regions · Sustainable mountain development

Introduction

Mountains are fragile ecosystems with global importance as water towers for adjacent, densely populated lowlands. Mountains are sources of forests and timber, minerals, biodiversity hotspots, cultural diversity and are home to 600 million people, which correspond to 12% of the global human population (Huddleston et al. 2003). The majority of mountain people live in developing countries and are among the world's poorest and most disadvantaged people due to harsh climatic and environmental conditions, political, social and economic marginalization and lack of access to health and education services (Veith et al. 2011). Mountains are therefore crucial regions for sustainable development and human well-being regarding food security and poverty mitigation (Singh et al. 2011).

However, mountain regions are prone to natural disasters, and they are exposed to multiple hazards such as avalanches, landslides, floods, debris flows and glacial lake outbursts (Kohler and Maselli 2009). Thus, the projected global temperature increase will strongly influence the frequency and intensity of natural disasters in mountain regions, especially with regard to hydro-meteorological events. The United Nations International Strategy for Disaster Reduction (UNISDR 2009a) defines natural hazards as:

> Any natural process or phenomenon that may cause loss of life, injury or other health impacts, property damage, loss of livelihoods and services, social and economic disruption or environmental damage.

Whereas the term disaster is defined as

> A serious disruption of the functioning of a community or a society involving widespread human, material, economic or environmental losses or impacts which exceed the ability of the affected community or society to cope using its own resources.

A natural hazard, therefore, does not necessarily cause a disaster. Natural disasters are the consequences of events triggered by natural hazards that overcome local response capacities within a vulnerable and exposed population and seriously affect the social, political and economic development of a region. Natural disasters occur worldwide, and economic losses due to extreme natural hazards have increased substantially in recent decades (Kron 2000; IPCC 2012, 2014). In response to further warming, many climate- and weather-extremes are expected to increase in frequency and severity in the ongoing century (IPCC 2012). Globally, the highest death toll due to natural disasters is concentrated in developing countries (Alcántara-Ayala 2002).

A number of studies (e.g. Kääb et al. 2005; Carrivick and Tweed 2016) indicate a continuous threat from glacial hazards to human lives and infrastructure in high mountain regions.

Depending on their tectonic and geomorphological situation and their climatic conditions, the hazard potential varies greatly from one mountain region to the other, from one valley to the other. Various studies (e.g. IPCC 2012; Kohler et al. 2014) determine that the increases of natural disasters are directly related to human activity. For example, population change, urbanization or environmental degradation are among key drivers for this increasing disaster trend observed in the past (Huppert and Sparks 2006; IPCC 2014). Hence, damage due to hazards in mountain regions will increase irrespective of global warming, especially in regions where population is growing and infrastructure is expanding within exposed locations.

For a systematic registration of these events, various global, regional and local disaster databases record and store information about occurrence and impacts of natural disasters. Comprehensive disaster databases indicate worldwide trends with an increasing number of reported events, people affected and economic loss, but a generally decreasing number of reported fatalities in the last decades (IFRC 2005; Munich 2012; Fuchs et al. 2013). Disaster databases help to identify disaster-prone areas and destructive hazards by a number of variables including human and economic losses. Information from databases enables analysis of occurrence and impacts of disasters over time and space and supports preparedness and the mitigation of events. They are a primary tool for the analysis of disaster characteristics and trends and support disaster risk reduction and climate change adaptation (Huggel et al. 2015b). Several loss and damage databases have been developed over the last several decades with data at global, regional, national and sub-national levels (UNDP 2013).

However, a number of studies (e.g. LA RED 2002; Below et al. 2010) indicate the lack of comparable data from different disaster databases because of inhomogeneity in scale, entry criteria, structure, coverage and information files. This absence of clear standards and definitions leads to inconsistent reliability and poor interoperability of diverse disaster data (Below et al. 2009). Hence, uniform standards, operability and terminology are essential for a reliable comparison of natural disasters in different disaster databases. Therefore, in 2007, the three global databases maintained by Munich Re, the Centre for Research on the Epidemiology of Disasters (CRED), and Swiss Re defined a common terminology in consultation with the United Nations Development Programme (UNDP), the Asian Disaster Reduction Centre (ADRC) and the United Nations International Strategy for Disaster Reduction (UNISDR). As a result of this standardization, natural hazard events are divided into four hazard families: geophysical, meteorological, hydrological and climatological events (Ismail-Zadeh et al. 2014). Therefore, for UNDP, the ideal loss and damage database has to be sustainable, continuous, credible, publicly accessible, quality assured and applicable to decision-making (UNDP 2013).

A number of disaster databases on a global, national and regional scale exist, but there is a research gap regarding their reliability for natural disasters occurring in mountain regions and especially for serving the needs of sustainable mountain development. Little has been known about weather- and climate-related natural disasters in mountain regions in the context of worldwide disaster databases. The present study is aimed at filling this knowledge gap and helps to better understand the importance of disaster occurrence in mountain regions, particularly in regard to ongoing global changes.

The first objective of this study comprises an analysis of the quality and completeness of the four selected databases (EM-DAT, NatCatSERVICE, DesInventar and Dartmouth) and investigates the reliability and main limitations of the various databases for weather- and climate-related natural disasters. The second objective focuses on the analysis of the occurrence and frequency of natural disasters in the time period 1980–2014 in the context of climatic and global changes in five selected mountain regions.

Study Regions

The focus of our study lies within five mountain regions: Hindu Kush-Himalaya, Andes, European Alps, the mountainous parts of Africa, and Central Asia. The selection is based on the research priority of the programme on Sustainable Mountain Development for Global Change (SMD4GC), to which this study is a contribution to. SMD4GC is the mountain programme by the Swiss Agency for Development and Cooperation (SDC), which aims at contributing to sustainable mountain development under uncertain changes in climatic, environmental and socio-economic conditions, focusing on poverty and risk reduction (Wehrli 2014).

Hindu Kush-Himalaya

The Hindu Kush-Himalayan (HKH) region covers an area of more than 4 million km^2, which is about 2.9% of the global land area and approximately 18% of the global mountain area (Singh et al. 2011). The Himalaya region consists of large thrust sheets formed from the basement of the advancing Indian continent, surmounted by many of the world's tallest peaks such as Mount Everest (8848 m a.s.l.), K2 (8611 m a.s.l.) and Annapurna (8091 m a.s.l.). The HKH region encompasses the mountains of eight South and East Asian countries including all of Nepal and Bhutan and the mountainous parts of Afghanistan, Bangladesh, China, India, Myanmar and Pakistan. The HKH region is often referred to as the "water tower of Asia" as it stores a large volume of water in the form of ice and snow, and the mountainous part is the source of many major river systems in the region such as the Amu Darya, Indus, Ganges, Brahmaputra, Mekong and Yangtze (Stäubli 2016).

Kulkarni et al. (2013) divided the HKH region into three subregions (western, central and eastern) primarily based on climate and topography; the western subregion has two major rainy seasons, whereas the two other zones only have one. The HKH region covers the largest glaciated areas in the world outside of the Polar Regions. The glaciers cover an area greater than 61,000 km^2, which represents about 30% of the total glaciated mountain area of the world (Singh et al. 2011). The HKH mountain area is home to 286 million people (Mountain Partnership 2014) with an annual growth of 2% in 2011 and with a continuing state of high birth and death rates with an increasing urban population growth rate. Almost all the mountain regions of the HKH are subsistence agricultural economics with 31% of the HKH living below the official poverty line (Karki et al. 2012).

Central Asia

The region of Central Asia covers an area of 4 million km^2 and has a population of 59 million (UNISDR 2009b) with an annual population growth of 0.7% in 2014 (mountain population 2012: 4 million; Mountain Partnership 2014). Central Asia includes the five countries Kazakhstan, Kyrgyzstan, Tajikistan, Turkmenistan and Uzbekistan. Mountains cover 800,000 km^2 or about 20% of the total area of Central Asia. The Pamir Mountains in Tajikistan and the Tien Shan in Kyrgyzstan (and adjacent countries) are the two major mountain ranges in this region. The highest peak of Tien Shan is Jengish Chokusu (7439 m a.s.l.), Somoni peak (7495 m a.s.l.) the highest in the Pamir Mountains, located in Kyrgyzstan, and Tajikistan, respectively. Kyrgyzstan with 90% mountain-covered area, Tajikistan with 93%, contain the greatest mountain areas and are important as water source regions for the two main river systems Syr Darya in the Tien Shan mountains and Amu Darya in the Pamir (Stäubli 2016).

Most parts of Central Asia have a semi-arid or arid climate, but the western parts are more humid. Glaciers cover in total an area of about 12,000–14,000 km^2 in Central Asia; in Kyrgyzstan glaciers extend over 4% and in Tajikistan over 6% of the territory (Batjargal et al. 2012). Mountain pastoralism is a significant part of the GDP (gross domestic product) in Kyrgyzstan and Tajikistan with a population below poverty line of 35% (Kerven et al. 2012).

African Mountains

Mountains in Africa generally occur widely scattered between the plateaus and plains that dominate the landscape. Approximately half of the African countries encompass mountains higher than 2000 m. The mountainous parts higher than 4500 m are concentrated in the north-western, central and eastern regions of the continent. These mountainous regions cover about 3 million km^2. The highest peak in the Atlas Mountains is Mount Toubkal at 4165 m a.s.l. The Ethiopian Highlands in north-eastern Africa include 90% of Ethiopia's arable lands and are occupied by 90% of the human population of the country (Hurni et al. 2010). The Muchinga (Mitumba) mountain range in East Africa and other mountain ranges surround the eastern and western Rifts including Mount Kilimanjaro (5895 m a.s.l.) and Mount Meru (4565 m a.s.l.) in Tanzania, Mount Kenya (5199 m a.s.l.) in Kenya, Mount Elgon (4321 m a.s.l.) on the border of Kenya and Uganda and the Rwenzori Mountains with Mount Stanley (5109 m a.s.l.), located on the border of Uganda and Congo. In southern Africa, the Drakensberg Mountains represent the highest elevations in South Africa with the highest peak being Thabana Ntlenyana (3482 m a.s.l.) (UNEP 2008).

The African mountain areas are home to 146 million people (Mountain Partnership 2014). The average population density in mountain areas is more than triple compared to the lowland areas with up to 40% of the population under the poverty line (UNEP 2015). Glacier distribution in Africa is limited to three specific geographic locations—the two volcanoes Mount Kenya and Kilimanjaro and the Rwenzori mountain range located in East Africa near the equator (UNEP 2013).

Andes

The Andes are the longest mountain range in the world with a length of about 8000 km, stretching along the entire South American continent. The Andes consist of a single mountain chain in Chile (Argentina) which widens in Peru and Bolivia to split into the eastern and western Cordilleras, separated by the high plateau of the Altiplano. Aconcagua (6968 m a.s.l.) is the highest peak of the Andes located in Argentina. The Andes cover an area of more than 2.5 million km^2 and are home to 73 million people (Mountain Partnership 2014) with a maximum of 50% of total population under poverty line in Peru (Stäubli 2016).

The tropical Andes can be divided into two climatic zones. The inner tropical zone (Colombia and Ecuador) receives relatively continuous precipitation throughout the year, while the outer tropical zone (Peru and Bolivia) experiences a dry season from May to September (subtropical influence) and a wet season from October to March. The tropical Andes had an estimated glacier area of about 1920 km^2 in the early 2000s, which corresponds to about 99% of all tropical glaciers in the world (Rabatel et al. 2013).

European Alps

The European Alps are a folded mountain range stretching along an arc of about 1200 km, from Nice to Vienna. They cover an area of about 191,000 km^2. 23 million people live in the European Alps (Mountain Partnership 2014), concentrated in towns and cities around the periphery and in low-lying valleys. Generally, migration is more important than natural population change, whereas population in the central and northern Alps is growing with a decrease of the eastern and southern Alps. Mont Blanc is the highest massif in the European Alps with an elevation of 4808 m a.s.l. The mountains and glaciers in the Alps are the reservoir of Europe's water with headwaters of the rivers Danube, Rhine, Po and Rhone being located in the region (Stäubli 2016). The Alpine glacier cover decreased from 4470 km^2 in 1850–2270 km^2 in 2000, which corresponds to an overall glacier area loss of almost 50% (Zemp et al. 2008).

Disaster Data and Methods

Disaster Databases Used in the Study

A number of disaster loss databases at global, regional, national and sub-national levels have been developed in the last several decades (UNDP 2013). The UNDP's Global Risk Identification Programme (GRIP) has identified a total number of 62 disaster databases worldwide with data collection on mortality and physical damage in the social, economic and infrastructure sectors (UNDP 2013). These 62 damage databases consist of five global inventories [EM-DAT, NatCatSERVICE, Sigma, Disaster Database Project and the online global disaster identifier database (GLIDE database)], two regional, 50 national, four sub-national and one event-based (Hurricane Mitch) database.

The current study refers to four disaster databases, three with a global coverage (EM-DAT, NatCatSERVICE as listed above, plus Dartmouth) and one database with regional coverage (DesInventar). EM-DAT and DesInventar both contain information of natural and technological hazards, whereas NatCatSERVICE only includes natural events, while only flood events are included in the Dartmouth database. Access to the databases varies. EM-DAT offers limited online data access through a range of search options. The raw data used for this study was available upon raw data request for the selected countries and is available in Excel format. DesInventar enables a country-wise data download in Excel format through their website. NatCatSERVICE offers limited access outside the insurance industry for scientific projects upon raw data request in Excel format and offers a range of analyses online. Dartmouth is a free, publicly accessible flood inventory with global coverage where flood data can be downloaded as an Excel file. While all databases contain the same overall information such as economic loss, social losses (people killed and affected), the focus of EM-DAT, DesInventar and Dartmouth are primarily on the humanitarian aspects, whereas the reinsurance database NatCatSERVICE focuses more on the material losses (Kron et al. 2012). Table 1 gives an overview of the four databases used in this study and analyzes disaster databases and their different entries.

EM-DAT (Emergency Disasters Database) has been maintained by the Centre for Research on the Epidemiology of Disasters (CRED) at the Université catholique de Louvain in Brussels, since 1988. It is the most complete, internationally accessible, public database on disaster loss at the national scale. The main objectives of this emergency disaster database are to serve the purposes of humanitarian action at national and international levels, to rationalize decision-making for disaster preparedness, and to provide an objective basis for vulnerability assessment and priority setting (Guha-Sapir et al. 2015). The database is based on various sources, including UN agencies, government sources, non-governmental organizations, insurance companies, research institutes and press agencies. The EM-DAT data recording system uses a unique identifier for each disaster and includes a disaster if one of the entry criteria is fulfilled (see Table 1; Below et al. 2009). Disasters in EM-DAT are defined as "a situation or event which overwhelms local capacity, necessitating a request to the national or international level for external assistance or is recognized as such by a multilateral agency or by at least two sources, such as national, regional or international assistance groups and the media" (Guha-Sapir et al. 2004).

DesInventar (Disaster Inventory System) is a conceptual and methodological tool which deals with natural disasters of all magnitudes on a local, national and regional scale and was developed by LA RED (Red de Estudios Sociales en Prevención de Desastres en América Latina) in 1994. DesInventar is managed by a regional group of academic and non-governmental actors and covers 16 countries in Latin America, the Caribbean and some in Africa and Asia. The DesInventar database reports disasters with any social loss. For the present study, the entry criterion for the data query in DesInventar has been modified according to the entry criterion of EM-DAT for a better comparability of these two datasets. The criteria are 10

Table 1 Overview of the four selected disaster databases

	EM-DAT	DesInventar	Dartmouth	NatCatSERVICE
Geographic coverage	Global	Regional (South America, Africa, Asia)	Global	Global
Hazard types	Natural and technological	Natural and technological	Floods	Natural
Disaster entry criteria	At least 10 people killed, and/or 100 people affected, and/or state of emergency/call for international assistance	No minimum threshold—any event that may have had any effect on life, property or infrastructure	Large floods with damage to structures/agriculture, and/or fatalities	Any property damage and/or any person severely affected (injured, dead); before 1970 only major events
Principal data source	Humanitarian agencies, governments, international media	Local/national media, agency and government reports	News, governmental, instrumental and remote sensing sources	Branch offices, insurance associations, insurance press, scientific sources, weather services
Period covered	1900–present, (good accuracy from 1980)	1970–present	1985–present	79–present, (good accuracy from 1980)
Management	University of Louvain (CRED)	Universities/NGOs (LA RED)	University of Colorado	Munich RE
Number of entries	>21,000	>44,000	4225 floods between 1985 and 2014 (mountain and non-mountain regions)	>35,000
Accessibility	Open (raw data request)	Open	Open	Limited

Source Guha-Sapir et al. (2015), LA RED (2015), Dartmouth Flood Observatory (2007), Below et al. (2009)

people missing or killed or 100 people affected or victims.

The **Dartmouth Flood Observatory** (DFO) is a global active archive of large flood events. DFO is a research project supported by the National Aeronautics and Space Administration (NASA) and Dartmouth University in Hanover, New Hampshire, USA and later at the University of Colorado. The main DFO objectives are to generate global remote sensing-based fresh water measurement and a registration of such information into a permanent archive. Further, DFO collaborates with humanitarian and water organizations for a better utility of information. The observatory uses satellite images to detect, map, measure and analyze extreme flood events on rivers worldwide. Dartmouth also provides annual catalogues, large-scale maps and images of river floods in the years from 1985 to the present (Prentzas 2006). The archive includes "large" flooding events with significant damage to structures or agriculture, length of reported intervals (decades) since the last similar event and/or fatalities (Dartmouth Flood Observatory 2015).

The **NatCatSERVICE** is a private disaster database maintained by the Munich Reinsurance Company (Munich RE). This global database collects information on natural disasters (excluding technological disasters). The entries cover a period from 79 AD to the present with good accuracy after 1980. The disasters are registered on a country and event level. The database is based on more than 200 sources worldwide, including national insurance companies, international agencies (e.g. UN, EU, Red Cross), NGOs, scientific sources and weather and warning services. Due to the availability of resources, NatCatSERVICE is able to provide detailed economic loss data. The database is partially accessible to the public, especially for clients of Munich RE. The access and search function of the database provides only information on a very limited number of natural disaster entries (Tschoegl et al. 2006). NatCatSERVICE includes disasters with any property damage and/or any person severely affected (injured, dead); before 1970 only major events are registered. The data entries are structured according to catastrophe classes reflecting the impact of a catastrophe in financial and human terms on a scale from 0 to 6. The catastrophe class 0 comprises natural disasters without financial or human losses, whereas class 6 comprises great and devastating natural catastrophes (Munich 2011). For our study, NatCatSERVICE provides global disaster data for mass movement disasters.

Assessment of Disaster Database Quality and Completeness

Information and data quality are among the most important characteristics of a disaster database. A study of 31 databases from Tschoegl et al. (2006) concluded that a lack of standardization in definitions and disaster classifications, inadequate accounts of methodology and variations in the availability of the sources diminished the usefulness of the information from databases (Smith 2013).

For Below et al. (2010), the basic entries in disaster databases are an event identification code, disaster type, geographical location, start and end dates of disaster occurrence and human, economic and structural impacts. The completeness of recorded information in the four databases is analyzed by calculating the percentage of records which contain information on human and economic impact, as well as missing values. The following four aspects have been studied for all event entries in the four databases for all regions: the geographical location, economic loss, date (start and end) and the number of zero values and empty fields. These four elements are particularly important for an identification of disasters in mountain regions with indications of human and/or economic losses. Our study includes only disaster entries with a clear geographical location (i.e., no empty field in the database, a clear identification regarding state, department or region is possible); otherwise, the entries were not taken into account. Information about the economic losses is very important because these numbers, in combination with the number of deaths, are the most frequently used parameters for tracking trends in disaster losses (UNDP 2013).

Definition of Mountain Regions

In order to analyze disaster events in mountain regions, a mountain layer has been superimposed on the worldwide disaster data. For our analysis, at least 50% of the area of every state, department or region must be covered by mountains (definition from Kapos et al. 2000, see below) in order for an entry with this geographic location to be recognized as a mountain disaster. Because of the extremely diverse landforms of mountains, it is difficult to achieve consistency in description and analysis of these formations, and numerous mountain definitions exist in the literature. Mountain regions can be defined as a conspicuous, elevated landform of high relative relief with steep slopes and variations in climate and vegetation zones (Price et al. 2013). The mountain definition applied in the current study (Fig. 1) follows the (UNEP) World Conservation Monitoring Centre (WCMC) and is based on Kapos et al. (2000), with the following three criteria: (1) elevation >2500 m a.s.l. (Class 1); (2) elevation 1500–2500 m a.s.l. and slope $\geq 2°$ (Class 2); (3) elevation 1000–1500 m a.s.l. and slope $\geq 5°$, or elevation 1000–1500 m a.s.l. and local elevation range >300 m a.s.l. (Class 3). To generate a mountain map of the study area based on the three mountain classes, the global SRTM digital elevation model (DEM) with a resolution of 1 km was applied. The lower limit of 1000 m a.s.l. for mountain areas was determined to exclude hilly and lowland regions (Stäubli 2016).

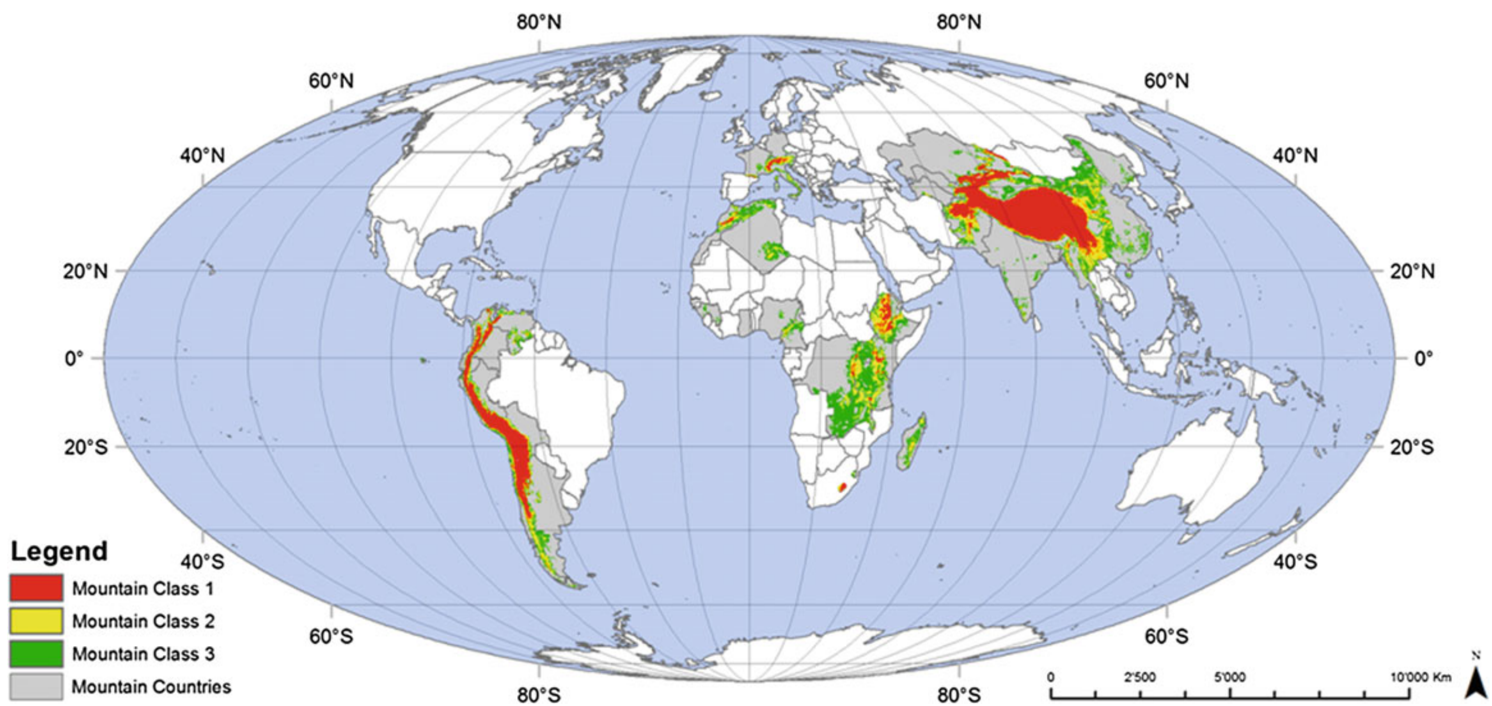

Fig. 1 Mountain regions based on the three mountain classes in the five study regions (in grey): Andes, Eastern and Northern Africa, European Alps, Central Asia and Hindu Kush-Himalaya

Classification of Disaster Types

The entries of EM-DAT and NatCatSERVICE are based on the same hierarchy and terminology of natural disasters. For the present study, only meteorological, hydrological and climatological disasters with the corresponding disaster types have been considered. Entry criterion for DesInventar has been modified according to the criterion of EM-DAT in order better compare the data. Dartmouth only contains information about flood events. Since the disaster types and natural processes in the disaster databases used were not all exactly the same, the following six categories have been generated:

– Storm (including tropical storm, strong wind, snow-, wind-, hail-, and thunderstorm)
– Flood (including spate)
– Mass movement wet (including landslide, avalanche and debris flow)
– Extreme temperature (including cold and heat wave)
– Drought
– Wild fire.

In general, the different disaster entries contain no information about the reason for their occurrence. For instance, when a flood is registered, there is no additional information available about the cause of this event. Hence, a flood could be triggered, for example, by a lake outburst or by a heavy precipitation event.

Analysis and Comparison of Regional Disaster Occurrence

In order to obtain an overview of the five mountain regions, the regional analysis aimed at investigating disaster trends with respect to disaster types and their occurrence in time and space. The regional analysis was based on the five mountain regions characterized according to geographic location, vulnerability, population and climate conditions. All records of natural disasters over a period from 1980 to 2014 were extracted from the EM-DAT database. The regional analysis is based on EM-DAT only, as EM-DAT is the only global database which provides freely available data, including across all six disaster types.

Quality and Completeness of Disaster Databases

The detailed comparative analysis of the three global and one regional disaster databases indicates a variety of strengths and weaknesses regarding their purpose, data sources, data reliability and organization. Discrepancy between data entries can be explained by the different methodologies, spatial resolution and base element definitions. Figure 2 summarizes database completeness regarding contents and number of registered disasters per database and mountain region. One main difficulty is related to the absence of entry criteria or impact threshold for entering a disaster event, except for the EM-DAT database. Nevertheless, the DesInventar methodology allows the collection of historical data on disaster losses in a systematic and homogeneous way at a low administrative level based on predefined definitions and classifications (UNDP 2013).

The accuracy and reliability of disaster data sources are highly influenced by the purposes of each database which results in different registered data entries. For instance, DesInventar and Dartmouth disaster entries are primarily based on newspaper information and media. However, data from journalists often do not come from proven sources and there is an unequal distribution of recorded information in different regions (Brauch et al. 2011). Thus, for example, more centrally located districts in the Andes would have a higher probability of being reported in newspapers than more marginally located districts. These circumstances may cause potential biases in the two databases (Glave et al. 2008). The strengths of the accessibility for EM-DAT, DesInventar and Dartmouth are the access to disaster data without any restrictions or charges.

The value of the EM-DAT database lies in the fact that it is the most complete recorded disaster

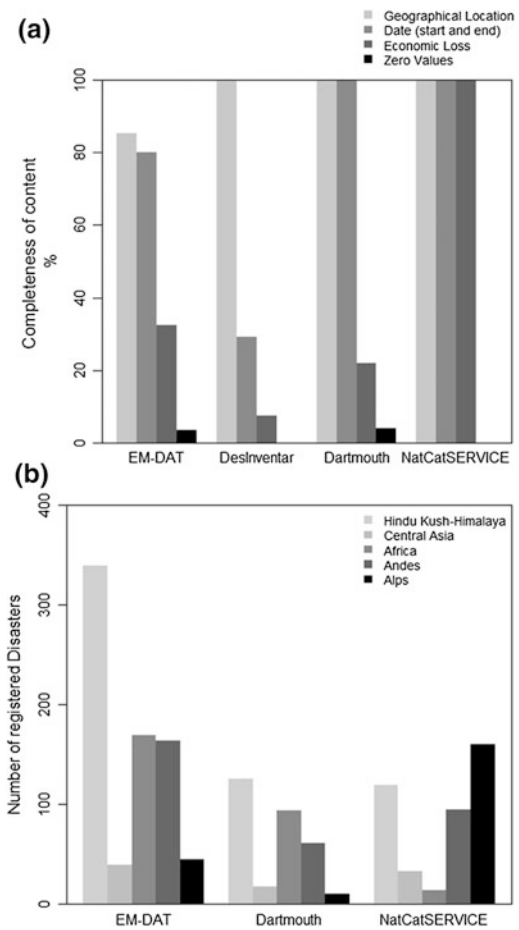

Fig. 2 Analysis of disaster database completeness of contents (**a**) and number of registered disasters per database and mountain region (**b**) for weather- and climate-related events during the time period 1980/1985–2011/2014 (source: EM-DAT, DesInventar, Dartmouth and NatCatSERVICE databases)

database with a global coverage and encompasses natural and technical (man-made) disasters. EM-DAT attributes disasters on state level, with additional indications to a particular region, whereas the spatial resolution of DesInventar identifies disasters on a regional, district or municipality level. The Dartmouth and NatCatSERVICE databases are geo-referenced with an exact geographical position expressed in latitudinal and longitudinal coordinates. The Dartmouth database provides flood disaster data without any restriction through their website with data from 1985 until the present in an Excel file. Dartmouth Flood Observatory (2004) provides good data reliability from 1985–1995, and even better after 1995. The value of the NatCatSERVICE database lies in the assessment of financial loss, representing the most important parameter for the reinsurance industry, as well as in its homogeneity and consistency of entry criteria applied over time. The magnitude of each loss (insured loss and economic loss) is registered for each event.

The ambiguities among the four databases indicate the relevance and the importance of comparing data from different sources (global and national databases) for a more reliable and comprehensive assessment of natural disasters. Therefore, database sources and structures, methodologies, purposes and history have to be analyzed carefully. However, there is a necessity for more standardized data entries, more homogenous and comparable loss data definitions and enhanced completeness of human and economic loss information.

Analysis of Regional Disaster Occurrence: The Diversity of Mountain Riskscapes

Mountain systems are very diverse and so is their exposure to natural hazards. Accordingly, the occurrence of major hydro-meteorological disasters between 1985 and 2014 in five selected mountain regions around the world (as recorded in the EM-DAT database) reveals a heterogeneous picture (Fig. 3). The impacts of these natural hazards on mountain people vary depending on their exposure and vulnerability.

As illustrated in Table 2, the HKH suffered from most events with a high resulting number of affected and killed people. However, the HKH is home for the greatest number of people with a population of up to 286 million. The total number of recorded events for Eastern and Northern Africa and the Andes is similar, with comparable numbers of people killed. However, there are many more people affected in Africa than in the Andes, corresponding to the higher population density in Africa. The number of disasters and

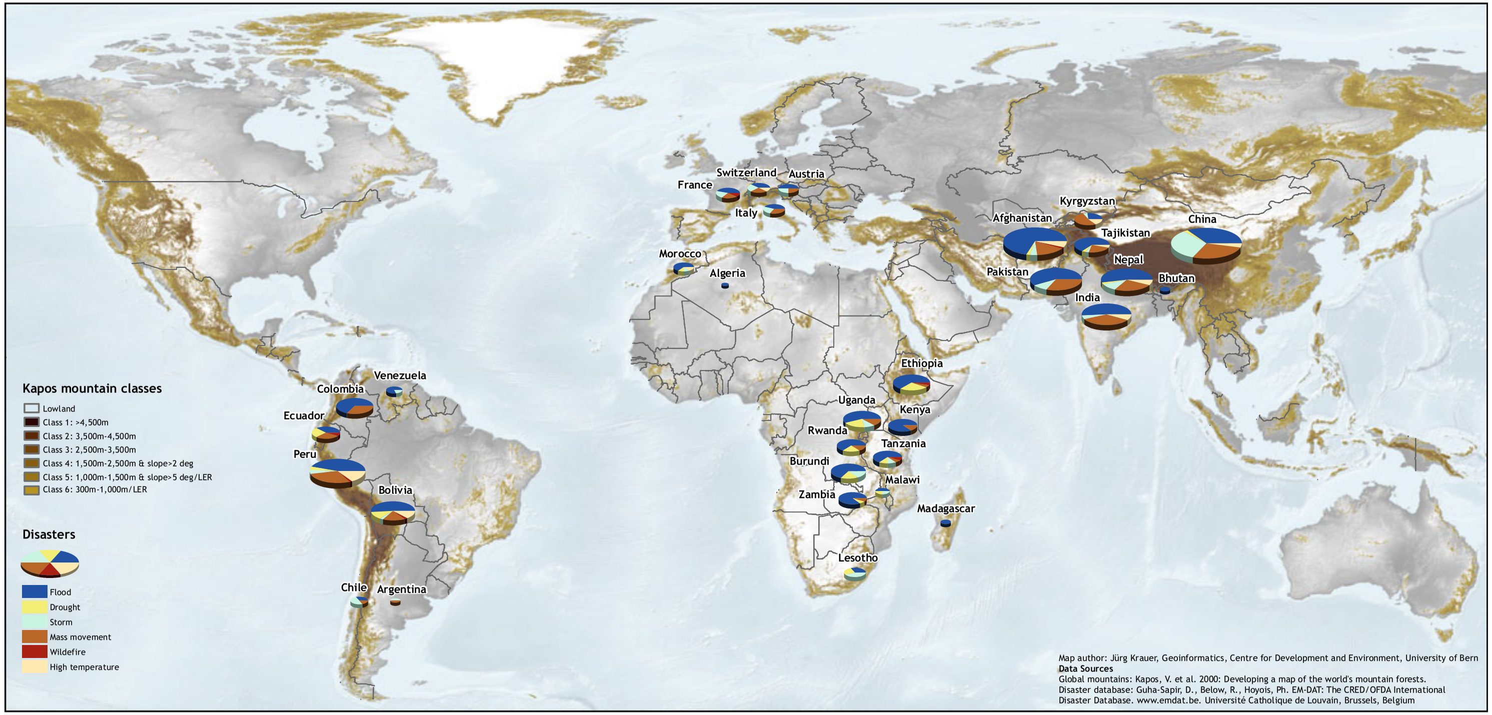

Fig. 3 Natural disaster affected the Andes, the European Alps, the Pamir Mountains and Tien Shan in Central Asia, the North and East African mountains and the Hindu Kush-Himalaya between 1985 and 2014 differently. Six types of natural disasters taken from EM-DAT have been considered: storm, flood, mass movement, extreme temperature, drought and wild fire. The size of the pie charts is relative to the number of disasters. LER: local elevation range > 300 m (7 km radius) (cartography: Jürg Krauer, Centre for Development and Environment (CDE), University of Bern, Switzerland)

Table 2 Major hydro-meteorological hazards (mass movement (including avalanches, landslides and debris flows), flood, storm, extreme temperature, drought and wild fire), and their impacts between 1985 and 2014 in five mountain regions based on EM-DAT (Guha-Sapir et al. 2015)

Mountain region	Number of disasters	Economic loss (and per event) in million USD	Number of people killed (and per capita)	Number of people affected (and per capita)	Mountain population, 2012[a]
Hindu Kush-Himalaya (HKH)	323	44,690.4 (138.4)	26,991 (0.009%)	165,694,879 (57.931%)	286,019,683
Eastern and Northern Africa	163	1246.8 (7.6)	4881 (0.003%)	76,127,779 (52.104%)	146,108,040
Andes	150	3138.4 (20.9)	6664 (0.009%)	13,006,871 (17.795%)	73,090,954
Central Asia	39	257.4 (6.6)	700 (0.017%)	3,518,763 (87.698%)	4,012,359
European Alps	38	7245.0 (190.7)	607 (0.003%)	33,011 (0.145%)	22,814,551

Smaller events although affecting people and the local economy are not included following the EM-DAT entry criteria
[a]Mountain population (without lowlands) adapted from Mountain Partnership (2014), for countries used in this study; mountain areas according to Kapos et al. (2000)

people killed for Central Asia and the European Alps are comparable, yet the per capita death toll is much higher for Central Asia than for the European Alps. The differences between these two regions are even stronger for people affected. From a sustainable development perspective, it should be noted that all these data do not capture the frequent small events that threaten people's livelihoods.

Monsoon-Triggered Floods in the HKH

The HKH region was most affected by disasters due to floods (52.6% of all registered disaster types), followed by mass movement (28.5%) and storm disasters (13%). The localization of these hazards shows three main affected zones: western zone (northern parts of Afghanistan and Pakistan), central zone (north-western India) and eastern zone (western China). The seasonal frequency of disasters is highly influenced by the monsoon pattern, as more than 80% of the annual precipitation is provided by the summer monsoon. Thus, the number of flood disasters in the mountainous regions of the HKH indicates a significant high frequency in July. For example, the 2013 Kedarnath disaster in northern India (see Box 1) was linked to early onset of heavy monsoon rainfall triggering catastrophic failure of a small moraine-dammed glacial lake (Allen et al. 2016). Alone in Nepal, 21 out of 1466 identified glacial lakes were assessed as potentially critical (ICIMOD 2011), and it is clear that increased infrastructure and habitation within high mountain regions of HKH is increasing the risk to such events (Schwanghart et al. 2016).

Central Asia: Mass Movements in Kyrgyzstan and Floods in Tajikistan

The mountainous parts of Central Asia are most affected by disasters due to floods (48.7%) and mass movements (35.9%). In Kyrgyzstan, landslides are the most widely distributed hazard type and about 5000 potentially active landslides sites have been identified, especially in the southern part of the country. Landslides are predominantly concentrated in the foothills of the Fergana Basin and mainly occur during the rainy season between fall and spring. Rainfall is the main triggering factor of landslides in the mountainous regions of Kyrgyzstan and Tajikistan. Tajikistan is most exposed to flood disasters, due to its mountainous topography with a high amount of precipitation and large number of existing glacier lakes. Floods in Tajikistan are often caused by outburst from glacial lakes, but other causes such as extraordinary meteorological conditions have also been assigned (see Box 2).

Box 1 Kedarnath flood disaster in northern India in June 2013

In June 2013, exceptionally heavy and continuous rains caused unprecedented damage to life and property in the Uttarakhand state of northern India and some parts of western Nepal. The maximum severity of the floods and damage occurred in the Kedarnath region (3553 m a.s.l.), which is the site of a very famous Hindu pilgrimage (Sati and Gahalaut 2013). The torrential rainfall between 15th and 17th June 2013 flooded the area causing excessive gulley erosion and sediment deposition. Due to continuous precipitation, large volumes of water transported a huge amount of sediments and debris from glacial moraines and surrounding areas to Kedarnath town. The main reason for the voluminous flow was the breach of Chorabari Lake (3960 m a.s.l.), which was dammed by the lateral moraine of the Chorabari glacier. The high volume of water caused an overflow and breach of the loose-moraine dam resulting in a glacial lake outburst flow (GLOF) (Uniyal 2013; Allen et al. 2016). This event killed and affected thousands of local people and pilgrims and destroyed infrastructure including highways and bridges. Socio-economic factors such as heavy deforestation, road construction, unplanned extension of settlement, mining and hydropower development may have increased the downstream damage (Shrestha et al. 2015).

Disaster data from the two global databases EM-DAT and Dartmouth Flood Observatory indicate numerous entries and make reference to the diverse information regarding geographical location and human and economic losses. The databases register three states which were equally affected by the flood such as Himachal Pradesh, Uttarakhand and Uttar Pradesh states. Additionally, the EM-DAT database registers five further states affected by the flood—Bihar and West Bengal states in north-northeast India and Gujarat, Karnataka and Kerala states located on the west coast of India. Both databases register the event as a flood, with EM-DAT declaring the disaster sub-type as a riverine flood with associated disasters of land-, mud-, snow-, and rock slides. The number of people killed according to EM-DAT is 6054, whereas Dartmouth registers 5748 people killed. Additionally, EM-DAT registers 4473 people injured and 500,000 affected. In contrast, Dartmouth only considers people displaced and registers a total of 75,000 people. Indications of economic loss only appear in the EM-DAT database with total damage of 1,100,000 million USD, and an insured damage of 500,000 million USD. As specific information about the flood, Dartmouth gives an affected area of about 131,743.41 km^2 and provides a severity index, the magnitude and an exact geographical location (centroid).

Box 2 Unusual 'heat wave' hitting high mountain areas in Tajikistan in July 2015

In July 2015, extraordinary meteorological conditions with high temperatures in the mountainous regions of Tajikistan led to intensified melting of ice and snow in high altitudes. The preliminary assessment suggests that the increased air temperature combined with unusually high amount of precipitation during the dry season triggered a series of mudflows and resulted in floods and increased levels of water in the rivers of the basins of Gunt, Panj, Vakhsh and Kafernigan.

While many settlements and infrastructure assets (irrigation infrastructure, roads, bridges, buildings and power lines) were affected all over Tajikistan, the high mountain valleys with steep slopes in the western Pamir (Gorno-Badakhshan Autonomous Oblast, GBAO) were most seriously hit, displacing a rather large number of people (~10,000 according to EM-DAT). The most remarkable flood event was registered in the village of Barsem, 2'400 m a.s.l., where a series of debris flows over a period of 4 days around July 18 had spilled some 1.5 million m^3 debris on the fan where the village is situated. While early assessments presumed a glacial lake outburst (GLOF) event, this hypothesis was mostly rejected later and melting of ice and snow as well as deteriorating permafrost in steep morainic depositions at high altitude leading to massive erosion in the ravine is being assumed as the cause (Zimmermann et al. 2016).

This event also formed a lake of 2 km length by damming the river Gunt, creating a lake outburst risk threatening the downstream settlements as well as a nearby hydropower station. A total of 80 houses were destroyed or flooded, leaving the same number of families without housing, and ~2 km of the main power line was completely destroyed. The international road connecting Khorog with Murgab and Osh was interrupted for 6 weeks.

The Dartmouth Flood Observatory registers not a single major event like the Barsem debris flows and damming of lake, but embraces the whole series of events happening in GBAO in July 2015. This event is listed with an ID number (*4273*) and is also time stamped with a *start* and *end* date. The main cause indicated is '*snow melt*' and refers to a single location in GBAO (*centre point*), not making reference to specific geographic locations other than the region and by linking to regional news sources. The EM-DAT database is less specific and lists the event as a *hydrological* disaster *flood* event with *two occurrences* which was affecting *10,802* people in Tajikistan. There is no time stamp or specific cause mentioned in the EM-DAT database.

Based on the analyzed case, the information provided in the global databases seems rather sparse and inconsistent, and while there might be some usefulness for research based on such global databases, the benefit for local communities and action on the ground remains limited. However, detailed documentation and analysis of such particular cases like the Barsem events will shed light into various issues related to future risks (particularly when considering climate change) and necessary structural and non-structural measures.

Drought and Flood Disasters in Eastern Africa

The mountain regions of East Africa are the most disaster-prone regions of Africa (Ethiopian and East African Highlands). The most frequent disasters in Africa are caused by floods (65%), followed by droughts (18.4%) and storms (8.6%). However, droughts affect much more people than floods and storms. Floods and droughts in some regions of Africa have been linked with the El Niño Southern Oscillation (ENSO), i.e. teleconnection patterns as far as to the equatorial Pacific Ocean (cf. Box 3 for ENSO influence in South America). There is a tendency for rainfall to be above average in most parts of East Africa during ENSO years and for rainfall deficits to occur during the following year; relatively wet conditions were observed during the

March–May and October–December rainfall seasons of the El Niño years (Indeje et al. 2000). Drought events may be underestimated as they are more difficult to define and do not destroy infrastructures. Hence drought events are less visible and data availability is not always ensured.

Disaster-Prone Central Andean Region

The Andes are most frequently affected by floods (50% of the registered disaster events) and mass movement disasters (28.7%), with most events taking place during the austral summer (December to February). The orographic effects of the Andean Cordillera lead to abundant precipitation at high elevations. These effects result in floods, causing damage in the densely populated foothills of the Andes. The Central Andes of Peru and Bolivia are most disaster-prone to natural disasters in the entire Andes. An important reason for the frequent occurrence of floods in South America are the El Niño and La Niña variations of the ENSO phenomenon. During events such as El Niño and La Niña, Latin America in general, and particularly the Andean region, is affected by many climatic events such as frosts, hailstorms, rainfall, landslides, floods, droughts, cold and heat waves. These events negatively affect the population in a significant way both personally, with damages to health, loss of human life, as well as material, as the destruction of houses and infrastructure, losses in agriculture and livestock, etc. For example, the impact of El Niño leads to increased rainfall particularly on the coasts of Ecuador, the northern part of Peru and the southern zones of Chile (see Boxes 3 and 4 for case studies from Peru, Bolivia and Chile).

Box 3 Impacts of the strong 2015–2016 El Niño event in Peru and Bolivia

The 2015–2016 El Niño event was considered among the three strongest such events recorded since 1950 (WMO 2015). It began its genesis in the second half of 2014 and had its full development in 2015, reaching its highest values of sea surface temperature (SST) anomalies in the last couple of months of that year. This event lasted approximately through the first half of 2016 and once the event terminated, the Pacific Ocean quickly switched to a neutral ENSO phase. Since the second semester of 2016, there was a slight cooling in the central equatorial Pacific that approached the threshold of a short and weak La Niña event. After this slight cooling period, the equatorial Pacific again warmed. By the end of January 2017, there were positive temperature anomalies in the South American coast, which added to the seasonal weakening of the South Pacific Anticyclone. This allowed the displacement of the intertropical convergence zone (ITZ) even more towards the south (CIIFEN 2017).

Peru

During the 2015–2016 El Niño event, the Andean region of Peru was affected by cold waves, droughts and floods from approximately May to July 2015. Heavy snow and frost affected the regions located above 3500 m a.s.l. The temperature in some places reached −15 °C, severely affecting life and health of the population, as well as basic services, livelihoods (agriculture and livestock) and infrastructure. Already by March 2016, a total of 20 people had died, 28 had been badly injured, 8729 injured and 103,267 affected (Redhum 2016). In total, approximately 165,710 people were affected and 100 lost their homes during the 2015–2016 El Niño phenomenon in several departments of the country. In addition, 529 homes were damaged, 11 collapsed and 11 became inhabitable (IFRC 2015). During the drought, the agricultural sector was the most affected one and several provinces declared emergencies. Therefore, the

Government of Peru (2016) launched a drought prevention and mitigation plan for 2016. By the end of March 2016, more than 13 million of soles ($\sim$4 million USD) had been invested in emergency response to the drought (WFP 2016a). On 30 September 2016, the Peruvian Government declared emergency due to the imminent danger of water shortages in several Arequipa districts.

Following the 2015–2016 El Niño event, on 11 December 2016, emergency was declared for seven Andean provinces in the Lima region due to water shortages. Conversely, shortly afterwards, too much water became also a problem, and by 17 January 2017, approximately 2645 people were affected and 1122 houses, 15.3 km of roads and 41.11 km of streets were damaged in Arequipa by persistent rainfalls.

Bolivia

According to reports from Bolivia's Civil Defence, around 100,000 households may have been affected by both excessive rainfall and drought in 109 municipalities in the country during the 2015–2016 El Niño. By 21 December 2015, a state of emergency was declared in 27 municipalities in three departments due to drought. In February 2016, the drought continued to affect the southern regions of Altiplano and Chaco. From May 2016, seven occidental regions were particularly affected, including the cities of Oruro and La Paz where more than 70,000 families were affected by the drought (OCHA 2016a). As of 31 July, 160,000 people were affected by the drought and 104 municipalities had declared state of emergencies. The most affected sectors were water distribution, sanitation, hygiene and food security (OCHA 2016b). By 22 September, an operation was executed to save and protect livelihoods of 40,000 people affected by the drought in the department of Oruro (WFP 2016b). On 21 November, the Government of Bolivia (2016) declared a state of emergency due to the water shortages in large strips of the country, considered to be the worst drought in 25 years. By the end of 2016, the drought had affected 173 of the 339 municipalities in eight provinces.

Directly linking large-scale weather or climate phenomena to disaster losses is complex, but the Ministry of Defence of Bolivia has concluded that the severe weather conditions caused by the 2015–2016 El Niño event directly affected around 60,000 people in Bolivia and left 19 dead between November 2015 and March 2016. Likewise, 31,000 hectares of crops and 15,800 heads of cattle were affected according to a report by the Civil Defence (Pan American Health Organization 2016).

Box 4 Flash floods and mudflows in northern Chile in March 2015

Between 24 and 26 March 2015 when the so-called Bolivian or Altiplano winter ended, and as a product of a segregated atmospheric low-pressure area where cold air at high elevation was hit by warm and moist air coming from the Amazon basin, a series of devastating floods (flash floods) with a statistical recurrence period of 15–20 years occurred in the Atacama region (75,166 km^2) in northern Chile, in the most arid desert of the world. Engineering works in the Copiapó riverbed conducted during the last 10–15 years, mainly near the confluence of the Quebrada Paipote (tributary river) with the main river, have reduced the overall run-off capacity of the system. During the great flood of March 2015, both the Copiapó River and the Quebrada Paipote overflowed. Much of the inundation in the city of Copiapó was in fact derived from the Quebrada Paipote and not from the overflow of the Copiapó River (Tassara et al. 2016). 50% of the urban area of Copiapó was affected by this event. The Chilean National Geology and Mining

Service (Sernageomin) registered a run-off of 1200 m^3/s of the Quebrada Paipote on 25 March 2015 (Quebrada Paipote is a dry riverbed; it flows only when precipitation in the Altiplano is abundant). The impact generated by the hydro-meteorological phenomenon affected several cities at the coast and in the mountains, including the city of Copiapó. The development of industrial mining activities, urban growth, watershed interventions and the degree of exposure of the population and its infrastructures underline the importance of priorities in territorial planning, especially in the new context of adaptation to climate change. After this hydro-meteorological event, water remedial works and cleaning of the Quebrada Paipote were carried out, allowing that the rains of January 2017 did not produce any damages.

Disaster data from one national source and two global databases provide information on the areas affected, and the social and economic losses. At the national level, Sernageomin describes the event in the "First National Cadastre of Natural Disasters" published in 2017. This publication registers the main disasters related to geologic processes in Chile since 1980 (Sernageomin 2017). At the global level, the event is registered by EM-DAT and the Dartmouth Flood Observatory (DFO). In all cases, the event is described as a flash flood/mudslide caused by heavy rainfall. According to Sernageomin, the event mainly affected the cities of Copiapó and Chañaral, and other locations in the region of Atacama. EM-DAT and Dartmouth indicate that the event affected three regions in northern Chile (Atacama, Antofagasta and Coquimbo), without specifying differences in the level of damages and losses. The number of people killed according to EM-DAT is 178, whereas Dartmouth registers 27 and Sernageomin 28 people killed. The latter also registers 59 missing. Additionally, EM-DAT indicates 193,881 people affected. Dartmouth registers a total of 29,741 people affected and 2514 displaced. Sernageomin does not provide information on the number of affected people. Dartmouth also provides information on the number of homes destroyed (2071) and damaged (6254). Indications of economic losses appear in Sernageomin and EM-DAT records with a total of 1500 million USD. EM-DAT also provides information on insured losses (500 million USD). Data reported by Sernageomin was provided by the Chilean National Treasury Department. It is worth noting that according to this source, the value corresponds to budget reallocations (1000 million USD) and resources obtained from national funds (500 million USD) used for the response and rehabilitation of the affected areas. In other words, the value would not represent the total damages. In terms of specific information about the flood, Dartmouth gives the duration in days of the event (15 days, from March 25 to April 8), an affected area of about 154,773 km^2 and provides a severity index and the magnitude.

European Alps: Flood and Avalanche Disasters

According to EM-DAT, floods (44.7%), mass movements (28.9%) and storms (21.1%) occur most frequently in the European Alps. The impacts of the orographic effects with concentrated rain on the windward side of mountains are important with significant impacts on lowland areas, especially riverine floods. Most mass movement and flood events in the European Alps occurred during winter and early spring months (December to April), due to the combination of meltwater from snow with extreme precipitation events.

Comparison of the Five Mountain Regions Through Time

Figure 4 shows the weather- and climate-related disasters in the five selected mountain regions from 1985 to 2014, as recorded in the EM-DAT database. The African countries (solid black line) exhibit a low number of disasters in the first 10 years with a fluctuation between one and three events. After 1995, the line indicates an irregular increasing trend until the peak in 2006 with 17 disasters. Afterwards, there is a decreasing trend until a lower level is reached again in 2014. The disaster trend in the European Alps (black dashed) during the 30 years period exhibits a very low disaster fluctuation between zero and four disasters per year, the latter occurring in the years 1987 and 2000. The Andes (black dotted) indicates a discontinuous fluctuation over the whole time period with the highest number of disaster occurrences in 2001. There is a minimum number of disasters in the Andes of two events per year. In Central Asia (blue solid line), the relatively low disaster frequency fluctuates between zero and four events per year, the latter occurring in the years 2004 and 2005. The HKH region (blue dashed) indicates a gradually increasing trend over the whole time period with a maximum of 25 disasters in the year 2005.

The spatiotemporal trends of disaster occurrence in the five mountain regions on a country level over the time period 1985–2014 are illustrated in Fig. 5. The results of the spatiotemporal occurrence of disasters indicate that the three most disaster-prone regions arc the Andes, the mountainous parts of East Africa and the HKH region.

Climate Change Increasing Risks of Natural Hazards

EM-DAT reveals a clear increasing trend in disaster frequency over the past three decades, most significantly for the HKH region (cf. Figs. 4 and 5). While some individual disasters such as the Kedarnath flood (see Box 1) have been robustly linked to changes in climate (Singh et al. 2014), there is generally insufficient evidence to attribute any overall increasing disaster frequency to climate change. Poor land

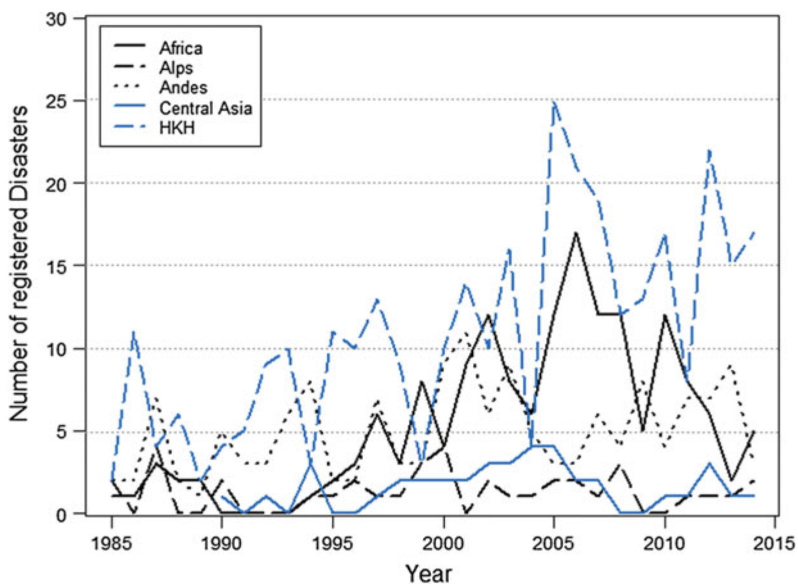

Fig. 4 Number of weather- and climate-related disasters in the five selected mountain regions for the time period 1985 (Central Asia from 1990) to 2014 (*Source* EM-DAT database)

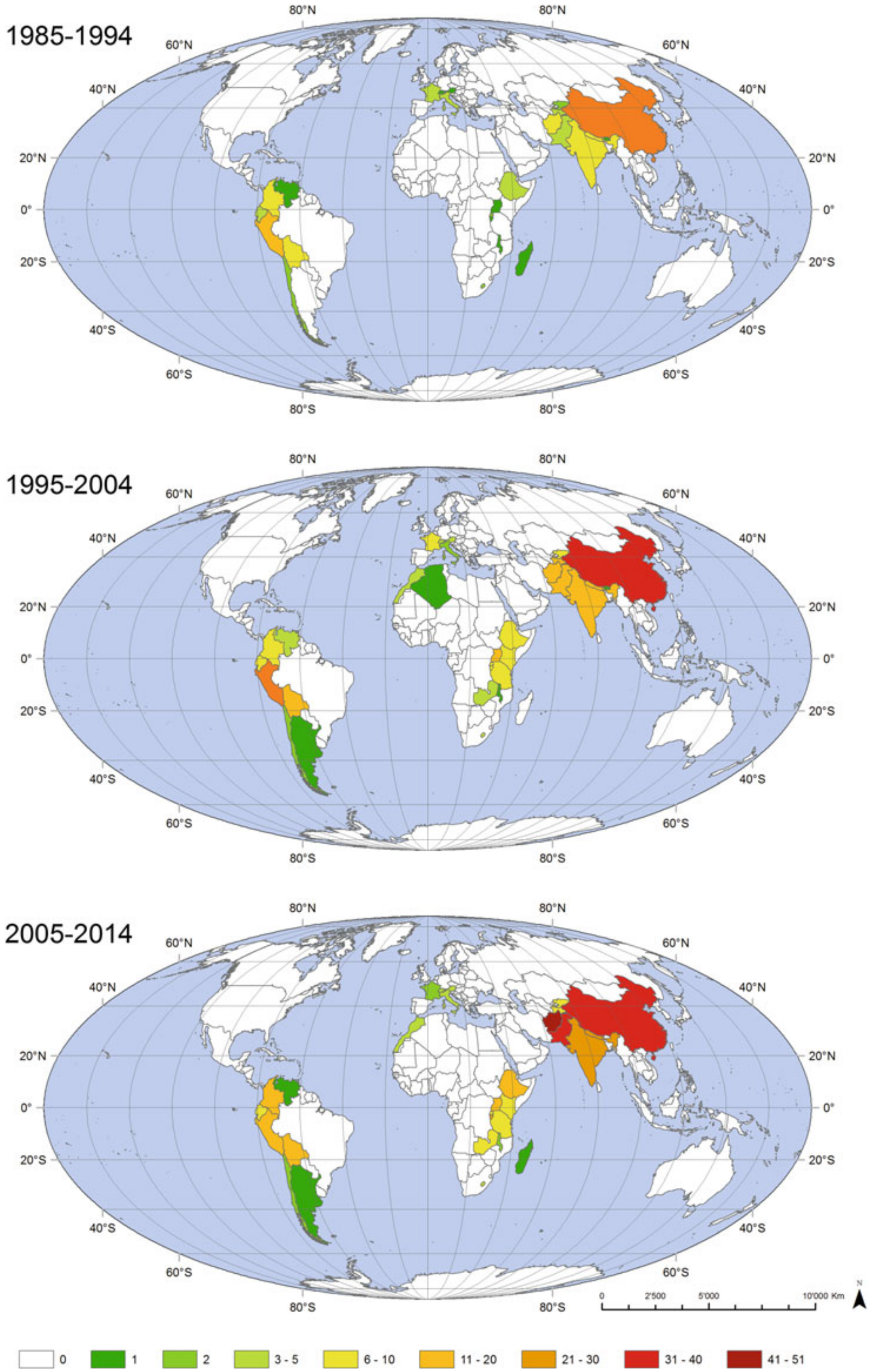

Fig. 5 Spatiotemporal trends of disaster occurrence in the five mountain regions at the level of countries over the time period 1985–2014 (*Source* EM-DAT database)

management practices and increasing exposure of people and assets could equally be important drivers of any apparent trend in disasters, while the recording of disaster events may also have become more reliable over recent years. Nonetheless, our understanding of physical processes and scenario modelling suggests continued climate change will lead to vastly altered mountain landscapes in the future, with associated implications for hazards and impacts on livelihoods and sustainable mountain development.

Future impacts of climatic change on physical systems will affect water, snow and ice and will lead to changes in the frequency and intensity of natural hazards (IPCC 2014). Changes in glaciers, snow and permafrost and corresponding impacts on natural hazards in high mountain systems are among the most directly visible signals of global warming and may seriously affect human activities (Haeberli and Beniston 1998; Kääb et al. 2005; Huggel et al. 2015a). Furthermore, with growing population, land-use changes and higher exposure, the frequencies and intensities of natural disasters in mountain areas are expected to increase in future.

There is a high probability that the risks of natural hazards will increase in the future both as a consequence of projected climate change, and additional stressors such as poor land-use practices and governance, or tourism expansion, and ecosystem degradation. Climate change will alter the magnitude and frequency of hydro-meteorological hazards owing to projected increases in extremes of temperature and precipitation in many mountain regions. While temperature extremes, and thereby related extreme melt events (short- or long-term, e.g. snow melt in spring, or extreme glacier melt during summer heat wave), are projected to increase globally, there is greater uncertainty and variation in future projections of heavy rainfall events (Seneviratne et al. 2012). In general, the climate models show a trend of currently wet regions getting wetter, and dry regions becoming dryer, meaning flooding and landslides can be expected to increase most dramatically across tropical mountain regions.

Irrespective of extremes, the ongoing retreat of glaciers and degradation of permafrost in response to changes in global mean temperature will lead to further hazards in high mountain regions (Korup 2014). As just one example, new glacial lakes will continue to expand in response to warming, meaning that the risk of ice or rock avalanches smashing into a lake and triggering catastrophic downstream flooding is of paramount concern across populated high mountain regions of Asia, North and South America and Europe (Haeberli et al. 2016).

Conclusions

The comparative analysis of the quality and completeness of the four selected databases (EM-DAT, NatCatSERVICE, DesInventar and Dartmouth), for weather- and climate-related natural disasters, identifies the numbers of fatalities as the most reliable loss parameters, whereby the number of people affected and the economic loss are less trustworthy and highly dependent on the purposes of each databases. The study emphasizes the main limitations in using such data for informing sustainable mountain development, such as the inhomogeneity in database definitions, spatial resolutions, database purposes and reveals the lack of data registration for human and economic losses.

The regional analysis and the disaster risk statistics in the time period 1980–2014 emphasize that floods and mass movement (avalanche, landslide and debris flow) disasters are most frequent and imply the highest relative threat for mountain people. Although the number of registered disasters has generally increased, the number of fatalities is stable, whereas the number of affected people shows an increased trend over the observed time period. Investigation of the occurrence of natural disasters in the five mountainous regions with data from the EM-DAT database indicated the highest absolute number of disasters for the Hindu Kush-Himalayan (HKH) region. However, note that if we consider the number of recorded disasters per capita, Central Asia was affected the most of all five mountain regions.

The disaster frequency from 1985–2014 indicated an increasing trend of weather- and climate-related disasters for the most disaster-prone regions of the HKH, Andes and African mountains, whereas no obvious trends could be recognized in the European Alps and the mountainous parts of Central Asia, where hazards were registered with a lower frequency. In future, damage due to hazards in mountain regions will increase irrespective of global warming, in regions where populations are growing and infrastructure is developed at exposed locations.

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Influence of Climate Change on Environmental Hazards and Human Well-Being in the Urban Areas—Warsaw Case Study Versus General Problems

Bożena Degórska and Marek Degórski

Abstract

During relatively rapid changes of climate, urbanised areas are particularly vulnerable to increasing frequency of heatwaves and intensification of torrential rainfalls. Such areas are characterised by the high density of population, specific spatial structure, with a large share of built-up areas and decreasing share of biologically active compounds. This results in an enlargement of the areas under the impact of urban heat island, which as a consequence of a synergy effect with ageing residents triggers the lowering of the quality of human life and even increased mortality risk in terms of inflow of hot air waves. The aim of this presentation is to show on the example of Warsaw, how changes in land use structure during the next years may worsen the quality of life of residents, increase the risk of floods or increase the risk of elderly people and children mortality due to heatwaves. Moreover, the demographic standing of Polish cities will be shown in terms of the structure of inhabitants' age. Particular attention will be driven to the issues of changes in land cover, the functioning of ecological corridors and wedges aerating the city, with urban sprawl as a result of strong sub-urbanisation processes. Negative consequences of climate changes will be presented along with proposals of adaptations of the environmental system to their courses.

Keywords

Climate change · Environmental hazards · Urban area · Water shortages
Green infrastructure · Warsaw

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Introduction

In the face of climate changes, a matter of key importance from the societal point of view is the functioning of areas and environments characterised by the highest densities of population and shaped structurally and spatially to an extreme degree by human activity, i.e. towns and cities. Frequently, there is overpopulation—pure and simple—in these areas, with densities even in excess of 20,000 inhabitants per km^2, as, for example, in Monaco. In such areas, there are large numbers of buildings in very limited areas, as well as technical infrastructure and hence a specific topoclimate that is seen to differ from that of open areas—not least in terms of spatial breakdowns for air temperature, precipitation totals and wind strengths EEA (2012). On the other hand, there remain many local natural factors capable of shaping the climate of an urban area, such as relief and land cover, the presence or absence of bodies of water, the extent of the remaining biologically active land surface. The climate of a town or city is also influenced by elements associated with human activity, first and foremost the two main sectors of the economy termed industry and transport, which are both very much concentrated in urban areas and feed the air with huge quantities of pollutants of many different kinds.

A consequence of air pollution is the appearance of phenomena that are at once ecologically and economically harmful and damaging to human health, such as smog, acid precipitation and above all events entailing the stagnation of hot air in the summer period. Together these serve to increase the mortality rates noted for city-dwellers during heatwaves, most especially where people are already suffering from cardiological complaints. This process has now assumed statistically significant dimensions in such Polish cities as Warsaw (Kuchcik and Degórski 2009). In line with models of the behaviour of climate in Europe (Greiving 2011), as well as forecasts to the year 2100 for the increased incidence of "tropical" nights (during which the temperature fails to fall below 20 °C) and very hot days (air hot waves are when temparature is higher them 35 °C) (Fischer and Schar 2010), it can be anticipated that the incidence of events of this kind is set to increase steadily (WMO 2013).

The aim of this paper is to present the most significant threats to the functioning of cities ascribable to changing climatic conditions, as well as the adaptive actions that will be essential if cities are to be prepared for ongoing phenomena and climatic processes. The analysis offered here pays particular attention to major issues attendant upon the dynamic relationship between urbanisation and climate change, with special account being taken of the ventilation and cooling of urban areas, the influence—for quality of life in cities—of ecological continuity and connectivity between urban and open areas, the role of green infrastructure in shaping urban space through the amelioration of negative effects, and the influence climatic conditions exert upon water systems in cities. The work described here has sought to use the example of Poland's capital, Warsaw, to illustrate the important role that green infrastructure plays in a city's spatial structure, as well as the functions served as an important element in urban space able to exert an influence on people's quality of life. The objective has thus been to determine the overall natural function discharged by the green infrastructure within the spatial structures of a representative urbanised area, as well as the role played in raising the quality of the lives enjoyed by inhabitants.

Methods

The analysis was carried out in relation to Warsaw, a city inhabited by 1.735 million people (as of 2014), and covering an area of 517.24 km^2 that still has very favourable natural linkages with surrounding areas. Ecological continuity with the systems beyond the city limits is assured by the valley of a large river (the Vistula)—also a major N-S axis of the city, as well as large complexes of woodland which serve as green lungs within Warsaw, taken together with even more extensive areas just beyond, like Kampinos National Park to the north-west, Mazowiecki Landscape Park to the south-east, the Legionowo

Forest to the north-east and the Chojnów Forests to the south-west (Fig. 1).

Analysis of environmental hazards and human well-being in the urban areas for Warsaw case study was done. Warsaw, as a biggest town in Poland, characterised by the most visible phenomena and processes of climate influence for the functioning and its spatial variability is a good example of urban area with many problems in relation to climate change and human well-being. In the analysis has taken into consideration dynamic of spatial development and land use of the city, the role of green infrastructure for minimising climate hazards and risk in the city, water shortages and other aspects of city functioning in climate stress conditions.

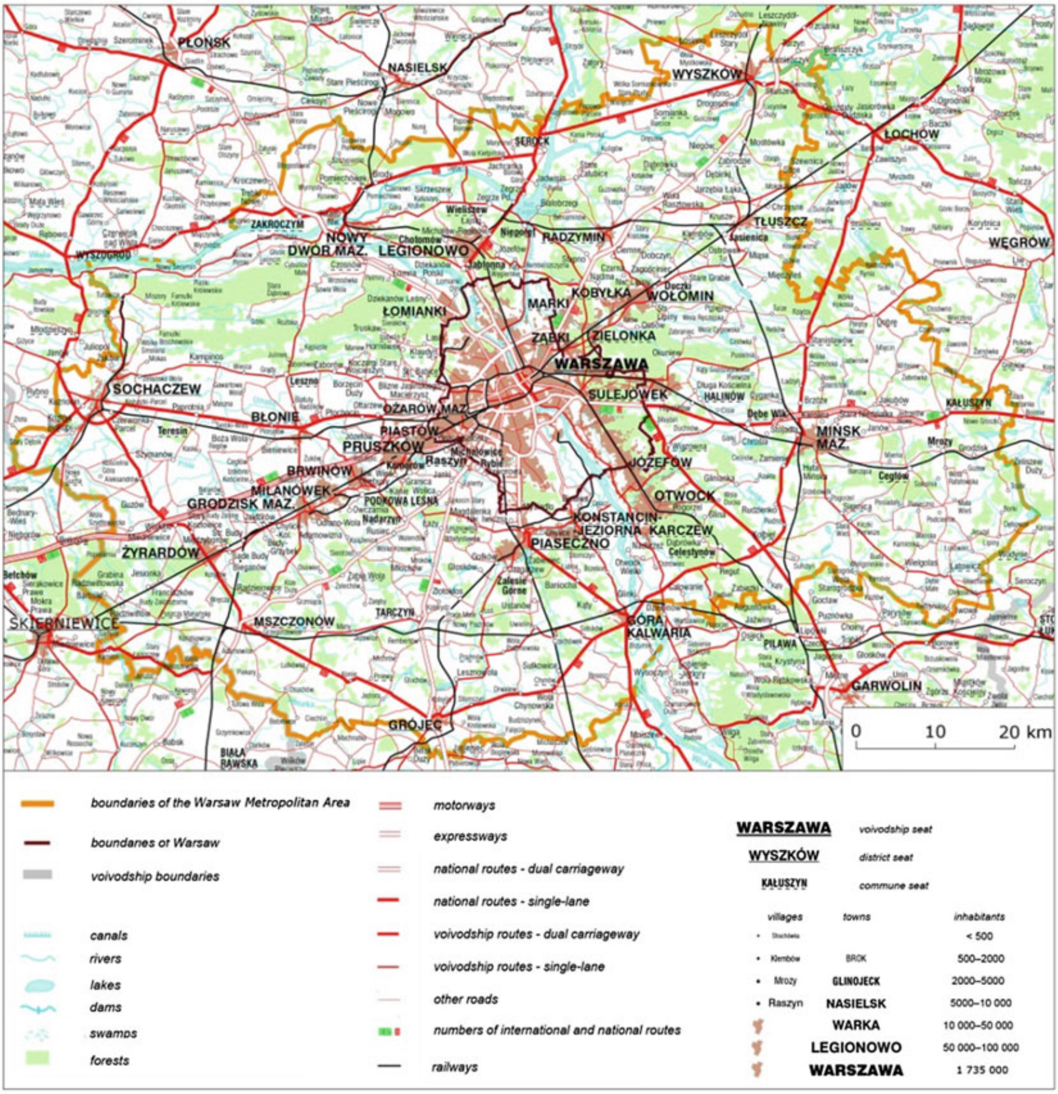

Fig. 1 Warsaw and its Metropolitan Area on the green area background and communication infrastructure (according to Degórska and Deręgowska 2007, updated)

Results

The Development of Cities and Their Sensitivity to Climate Change

The process of urbanisation ongoing in the last 200 years is one of the causes of a rapid increase in the number of town- and city-dwellers that the so-called demographic urbanisation entails. As the nineteenth century began, just 2.4% of the world's population was resident in towns and cities, but by 2007, the United Nations was beginning to maintain that more people were living in urban than rural areas, for the first time in history UN (2007). The same UN reporting anticipated that 60% of humanity would be living in towns and cities by 2030. Inevitably, such an increase in numbers of people has been associated with increased sizes of urban areas (the so-called spatial urbanisation), with the process often assuming the uncontrolled features of what has become known as "urban sprawl". Also, urban sprawl is very intensive in Warsaw Metropolitan Area (Degórska 2014)—(Fig. 2).

Different regions of the world are found to differ markedly in the above respect. In states enjoying only a limited level of economic and social development, those choosing to migrate to cities count on improved conditions for existence, but in fact themselves give rise to a process of overurbanisation, in that they live—at least initially—in districts whose features do not allow for a categorisation as truly urban, given the way they fail to meet many of the functional conditions necessary for a city. Such circumstances of overcrowding in the face of poorly developed technical and social infrastructure—as well as green infrastructure—constitute such a huge functional and spatial problem because of the impacts they exert on quality of life in the affected communities, as well as these people's security, not least as regards health, and the capacity to adjust to climate change (Degórska 2007). These are the same kinds of reasons for cities in the developed world to spare no effort in making cities liveable, citizen-friendly and capable of engendering a sense of safety and comfort.

Poland is at present characterised by an index for demographic urbanisation at around 60% (59.6% according to the last Census), though the trend has been downward—with a fall of around 3% from the peak noted at the end of the twentieth century. In line with the urbanisation indicator used by the UN, Poland is among states with a medium or high level of urbanisation (the limit value distinguishing the categories being at 60%). It nevertheless needs to be noted how the phenomenon of urbanisation is proceeding at varying intensities across Poland. There are regions that have been characterised by relatively strong processes of urbanisation for many years now, and in which the index of urbanisation rises by between 1 and 10%. To be mentioned among these areas is the Tri-City, or specifically the Gdańsk Metropolitan Area plus areas along the Baltic coast between Gdynia and Władysławowo; the Bydgoszcz-Toruń Metropolitan Area; the areas of the Szczecin, Poznań, Wrocław, Tarnów and Chełm agglomerations; as well as the northern, western and southern ring around Warsaw. The counterweight for these trends is provided by areas undergoing depopulation. A large efflux of the population is to be noted, not only in rural areas, but also in small towns—especially in eastern Poland, as well as in certain large agglomerations like that of Łódź (Degórska and Degórski 2015).

The total for the number of towns and cities in Poland stands currently (as of early 2015) at 915. Among these localities, there are just 7 cities with more than 400,000 inhabitants, as well as 40 with more than 100,000. This leaves the great majority of urban areas, which are effectively small or even very small towns of 10,000 inhabitants or less. Indeed, there are 109 "towns" with less than 2500 inhabitants each. In such localities, the issue of climate change is hardly tangible to inhabitants at all.

Equally, the vulnerability of urban areas to the negative consequences of climate change is greater where the process of spatial urbanisation is or has been intensive, and this is most particularly true of Poland's agglomerations and metropolitan areas. A very common result of

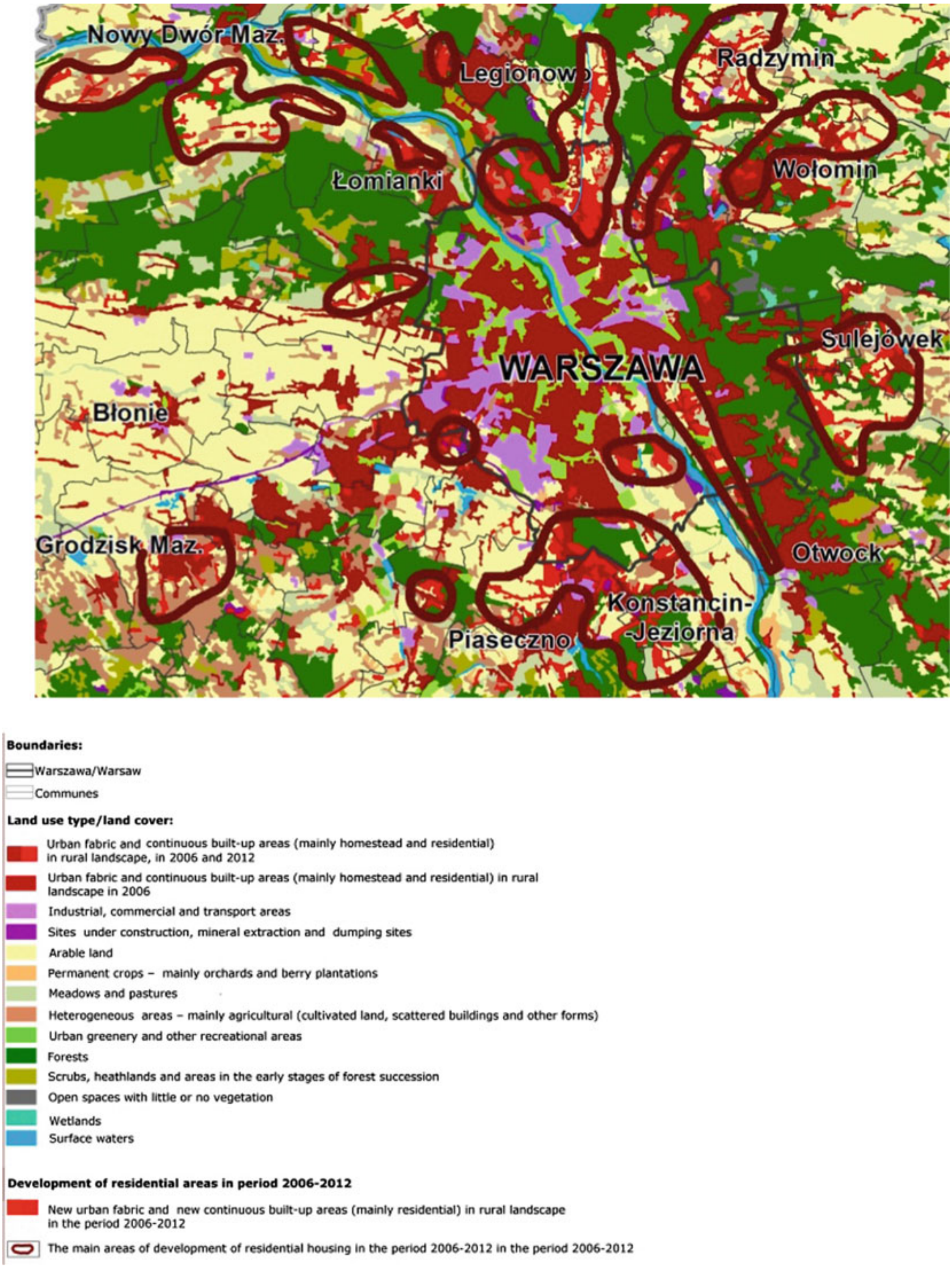

Fig. 2 Built-up areas in Warsaw and urban sprawl process in the period 2006–2012

urban spread or sprawl—everywhere in the world—is building in areas at risk of flooding, or else in remaining areas of greenery in the suburbs and on housing estates. Urban green space serves aesthetic functions, but also favours stabilisation of the heat balance. Its removal mostly leads to a sealing-off of soil under concrete and asphalt, with the effect that water retention is reduced and run-off enhanced. This compounds problems with the draining of wetlands for building, as well as the deliberate filling in of small ponds, and the canalisation and even burial of natural water courses. Then, there is also the huge pressure urbanisation exerts on open areas that can only contribute to the system ventilating a city for as long as they remain free of buildings.

Where "natural"—or at least open—areas become more and more limited in relation to the overall settled area, the natural potential for a city to be cooled is more and more impaired. Increased density of construction and the introduction of taller buildings (and hence a larger amount of vertical surface) than hitherto into suburban zones encourages absorption of the Sun's rays, reduces wind speeds and helps to give rise to canyon effects. The result is an enhancement of the urban heat island (UHI). Beyond that, the temperature increase is actively magnified in city centres by heating and ventilation systems serving as additional anthropogenic sources of heat pollution, as well as by the physical properties of the materials most often covering urban land (i.e. concrete and asphalt), which are known to absorb more solar radiation than they reflect.

Unfortunately, trends for change in the spatial structure of towns and cities are likely to be largely negative in character, where the quality of life of inhabitants is concerned. The pressure to build on and develop urban areas will continue to ensure the loss of biologically active surfaces and green infrastructure, with this process likely to prove a very intensive one in Poland's largest cities in particular. For example, among the least favourable forecast changes for Warsaw's green infrastructure through to the year 2070 is a loss of forest land and land planted with trees or shrubs from 17 to 14% of the city area—if the loss is mainly among the latter rather than the former, or even to 14% if forest is also subject to more major loss (Błażejczyk et al. 2014).

Furthermore, while private land under trees can be expected to be the first to lose this status unless the legal conditioning is changed, the pressure to build may even encourage inroads into the capital city's large, treasury-owned complexes of woodland or forest. At present, even land falling within the Mazowiecki Landscape Park is being encroached upon, while some of the anticipated losses of forest area will link up with the construction of road (including motorway) infrastructure that is already anticipated. The plans in question indeed foresee a further bisection of forest complexes in the aforementioned area enjoying Landscape Park designation.

Equally serious will be the major loss of open green areas that currently allow cleaner, fresher air to flow into Warsaw's urbanised core. It is already expected that, beyond ongoing redevelopment of parts of the city-centre area, Warsaw urbanisation will mainly take place on what remains farmland at the present time. The assessment is thus that the share of open land within the city limits of Warsaw (taken to include farmland) will decline markedly from around 50% now to just some 35–37%, with the main losses involved being of arable land.

All of these changes will undoubtedly lead to further areal expansion of the urban heat island, which has already enlarged greatly and become more persistent in the city area. According to Błażejczyk et al. (2014), it was present on almost 87% of days in a year throughout the 1981–2011 period, with the range being between 80% of winter days and 94% of those in the summer period. Additionally, during the one day difference between the minimum temperature in down town and peripheries (open space) could be few Celsius degrees. The value of UHI-index shows Fig. 3.

The urban heat island proves particularly dangerous for the elderly, as frequent sufferers from vascular and cardiac diseases and/or respiratory insufficiency. This is thus a population particularly prone to thermal stress, whose size is increasingly steadily. Ever-better and more

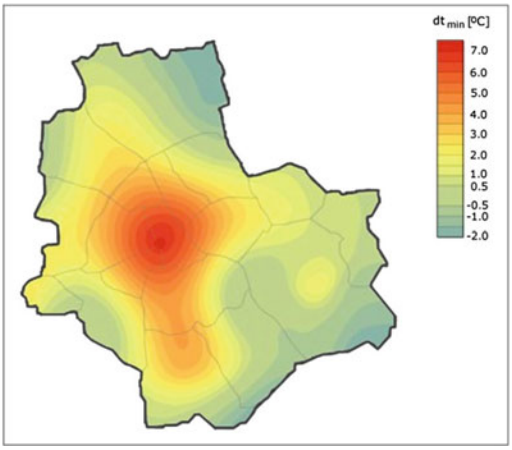

Fig. 3 Distribution of deviations minimum air temperature in the Warsaw area relative to the station Warszawa-Okęcie (outside the city) on 23 May 2011 (according: Błażejczyk et al. 2013)

accessible medical care ensures greater longevity of life, and there is a consequent increase in the proportions of the populations of urban agglomerations accounted for by the elderly. In order to determine the vulnerability of large cities associated with exposure to high temperatures, use is made of two measures:

- the absolute demographic heat-related health risk of a given city (ADHR), defined by the number of inhabitants aged up to 4 inclusive, as well as 65 or over,
- the demographic heat-related health risk (DHR)—defined by the share of all inhabitants in the given city that are aged up to 4 inclusive, as well as 65 or over.

Among the Polish cities, it is Warsaw that faces the worst demographic situation, given that it has the highest concentration of inhabitants exposed to a heat-related health risk, i.e. no fewer than 405,100 people, of which 223,500 are aged 75 and over. Further cities are Łódź, Kraków, Wrocław, Poznań and Gdańsk (Fig. 4). When it comes to the overall numbers of inhabitants facing risk as measured by the ADHR index, residents of Warsaw are seen to account for 17.4% of the total (Fig. 5).

Bearing in mind the synergistic impact on human health of high temperatures and simultaneous severe air pollution, the Polish cities made most vulnerable by transport and heavy industry are those located in the Upper Silesian agglomeration, but also Warsaw, Kraków and Łódź. It is in these areas that the most marked synergy between the two negative factors of pollution from transport and industry is to be observed. In turn, in the winter period, a third factor adding to those mentioned is municipal pollution from houses. It is ever more frequent for the result of this kind of activity to be a smog that is a tangible cause of lowered living standards for the inhabitants of cities. The health of the latter is harmed by such component elements as noxious chemical compounds, particulate matter (especially the tiny PM2.5 fraction) and high humidity, given that these encourage allergic reactions, can induce asthma and can lead to chronic bronchitis, respiratory impairment and higher incidences of certain types of cancer (Fig. 6).

Climate Change and Water Shortages

The World Water Council reports (drawn up in line with a proposal put forward at the 1977 Mar del Plata Conference of the United Nations) have since 1990 regarded Poland as one of the countries in deficit where the supply of water is concerned. Poland is in fact one of the least-blessed countries where water resources are concerned, there being 1600 m^3 of water per inhabitant in an average year, and less than 1450 m^3 in a dry year. This is less than half of the resources possessed by Spain, for example. Water resources are also decidedly scarcer than in the next-door Germany—a country which attaches great importance to systems providing for the management of precipitation waters.

Thus very much indicated in the case of Poland, given these modest water resources, is the adoption of solutions seeking to achieve the maximum possible retention of water in the environment. If this is to happen there will need to be a revitalisation of natural bodies of water, in

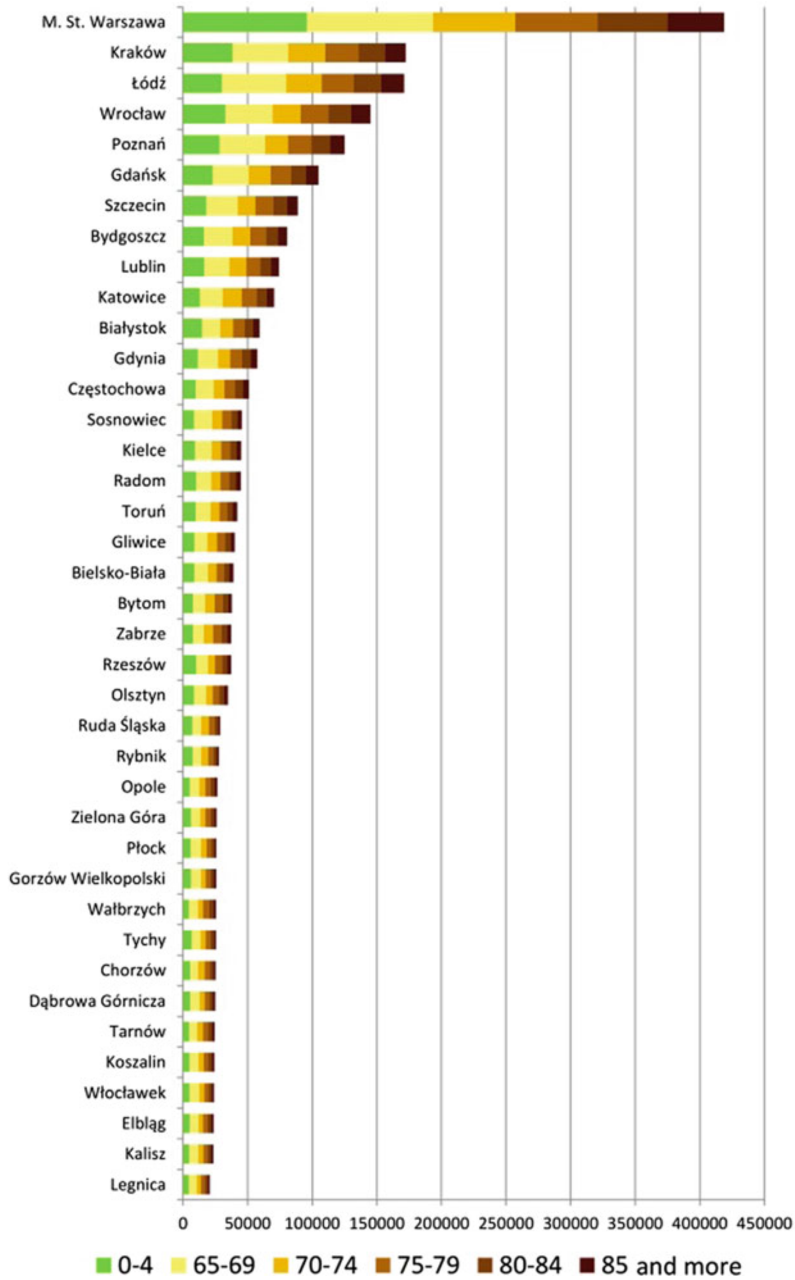

Fig. 4 Absolute demographic heat-related health risk (ADHR) in cities of over 100,000 inhabitants (as of December 2015)

such a way that structures are installed to facilitate "natural" water retention. In addition, in urbanised areas, there is a need to rationalise the utilisation of precipitation waters within the overall wider context of urban water management. Different European states have in fact

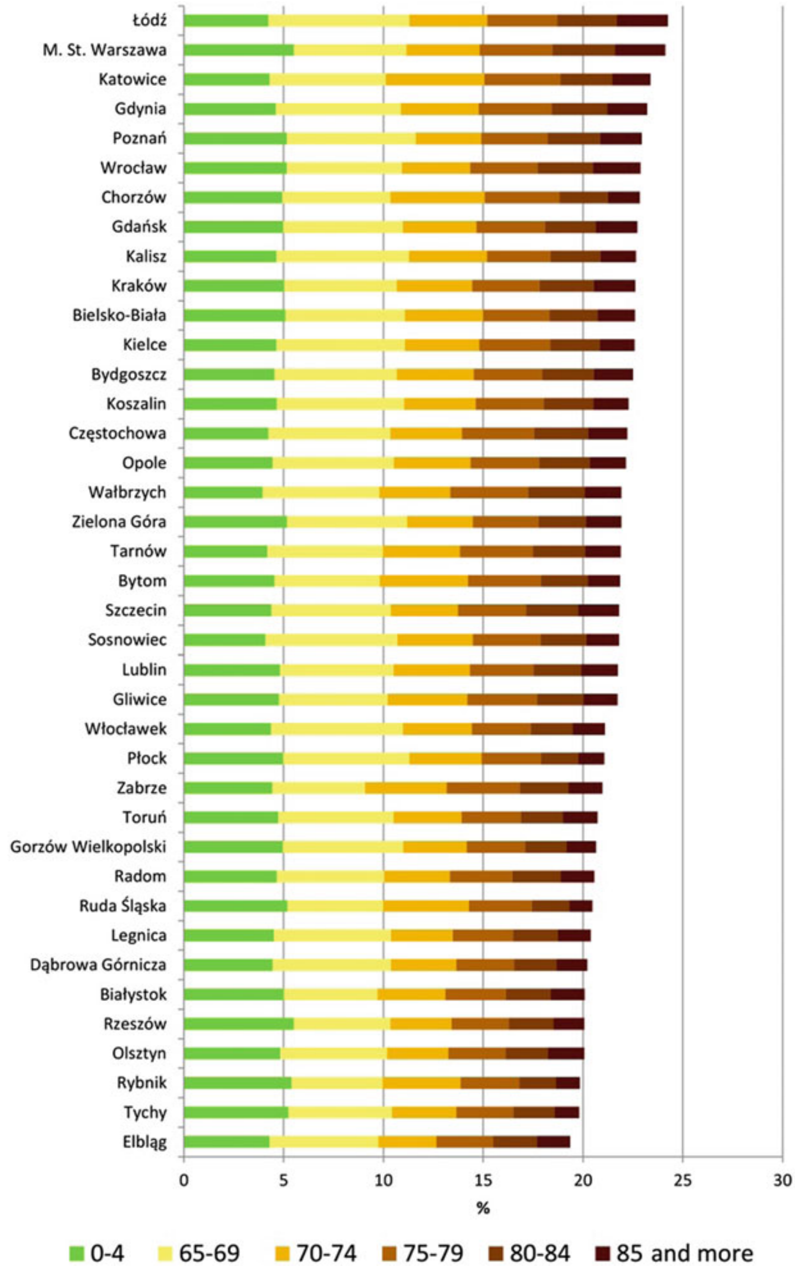

Fig. 5 Demographic heat-related health risk (DHR) in cities over 100,000 inhabitants (as of 31 December 2015)

come up with a wide range of solutions and measures by which rainwater can be better managed, including:

- the construction of reservoirs, be these of the retention or retention/infiltration types,
- the utilisation of precipitation water, for example, in the washing of cars or watering of gardens,
- “green roofs”,
- The “loosening” of hard surfaces (draining pavements) and the greening of yards.

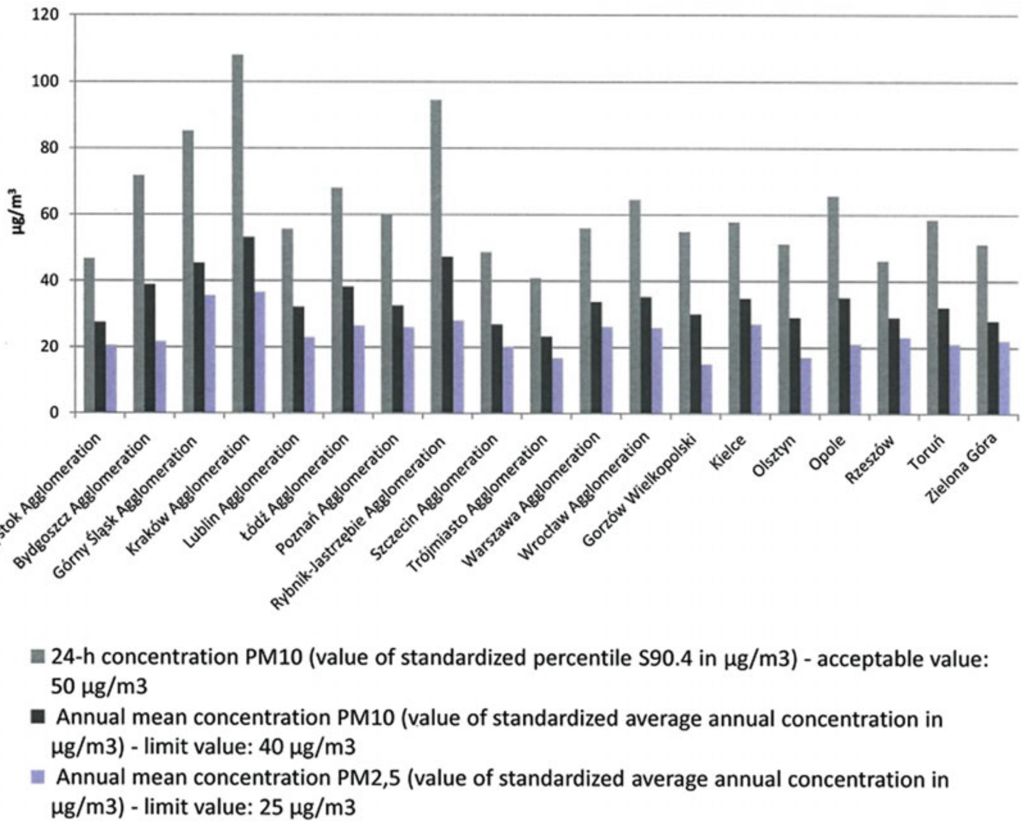

Fig. 6 Concentration of suspended particulate matter PM2.5 by agglomeration and cities in Poland for 2014

When rain falls on non-sealed surfaces, most of the water soaks straight down into the soil, from which it percolates slowly downwards to feed into supplies of groundwater. Only around 20% of this water runs off across surfaces to reach watercourses directly. In contrast, city land that is paved and concreted oversees around 80% of precipitation water contribute to immediate surface run-off, which rapidly finds its way into drainage ditches and watercourses, often giving rise to local flash flooding, especially when a true downpour or cloudburst takes place. It needs to be emphasised that, just as flawed water management in urbanised areas can a cause of flooding, so it can equally well underpin shortfalls in the supply of water, especially during periods of drought. Given Poland's present hydrological circumstances, the problem of water shortage as further exacerbated by climate change can give rise to great difficulties with constancy of supply of water to our country's large urban agglomerations.

Actions Adapting Cities to Climate Change, as Exemplified by Warsaw

In the view of the authors, the actions providing for mitigation or adaptation in the face of the negative impact of temperature increase in urban areas would be as follows:

– the preservation—within the spatial structure of the city—of areas that are not built up and thus capable of exerting an ameliorating influence on the processes heating up urban space, as well as limiting thermal stress through the facilitated movement of air;

- the preservation of extant areas of tall greenery, which allow for local-level lowering of temperature even in the immediate vicinity of buildings, thanks to the reduction in insolation that eases thermal stress in summer and help provide a respite for the bodies of sheltering inhabitants overburdened by heat;
- the introduction of open and tree-planted areas into districts slated for further intensive construction;
- the introduction of "green roofs" and "living walls" in areas with very high shares of contiguous built-up land, as well as activity to make good losses of green space associated with intensive construction;
- the raising of the energy efficiency of buildings;
- the lowering of the thermal conductivity of buildings through thermomodernisation, the modernisation of central-heating installations, insulation and the replacement of older windows;
- the installation of photovoltaic power stations on the roofs of public buildings;
- the ongoing modernisation of public-transport fleets;
- the preparation of urban infrastructure for the occurrence of higher wind speeds;
- the permanent monitoring of heat islands, and the establishment of a system providing the public with up-to-date information on the extent and severity of the phenomenon;
- the introduction of legal solutions and financial mechanisms by which buildings of public utility and dwellings alike can be fitted out with air conditioning units;
- the introduction of an early warning system in respect of enhanced risk of cardiological problems associated with heatwaves and the development of far-reaching urban heat island phenomena;
- the introduction of a system by which to assist the sick and elderly at the times of the onset of heatwaves and the development of far-reaching urban heat island phenomena.

A further, very important issue to be resolved rapidly in the context of climate change entails enhanced efficiency of the system by which rain falling on the city is intercepted and utilised. The whole area of Warsaw in fact faces difficulties with the management and discharge of precipitation waters. The main tasks to be pursued in this regard concern:

- optimisation of discharge through redevelopment—and hence a raising of the efficiency—of the system of stormwater drainage;
- the fuller utilisation of areas of green space or otherwise planted with trees in the creation of a shield that delays and slows down the run-off of waters;
- the regeneration and remodelling of the system serving in the small-scale retention of water.

The last point, entailing the remodelling and further development of small bodies of water, offers the best means of protecting against flooding, whether this is due to torrential rain or flood crests passing along rivers. To this end, it would seem worthwhile to support and continue with work already done by the Warsaw districts to revitalise and reconstruct existing ponds and lakes. Furthermore, where the technical capabilities are present, efforts should be made to raise the natural water-retentiveness of areas most threatened by flooding, by way of the impoundment of water in drainage channels and bodies of water alike, with the attendant development of installations by which the system as a whole can be steered to retain maximal amounts of water in the environment, rather than facilitate the run-off that causes land to be inundated abruptly from outside or beneath.

The issues of the interception and discharge of precipitation waters within Warsaw are very complex, given that receiving waters take the form of small streams, brooks, ditches or canals that are often present on private land, are put at risk should the run-off of water be much accelerated at times of heavy rainfall, are subject to reduced throughputs in periods with precipitation shortages (on account of the sealing of many surfaces within the urban parts of many drainage basins and the consequently reduced alimentation of groundwater) and are also markedly polluted. Furthermore, what remains of the system of designated drainage channels, still controlling the outflow of precipitation water, is mostly located on private land and is supposed to be kept in the appropriate technical state by the owner. Enforcing this kind of obligation is obviously a problem, and in many places, the drainage systems present previously have been ruined, or covered over altogether, with consequent disruption of water relations in the given areas.

Green Infrastructure

The Warsaw area is characterised by a high share of green infrastructure within the overall spatial structure of the city. The multifunctional role in shaping the urban system is one of the key factors promoting resistance to the threats posed by civilisation, above all (though not solely) climate change. With a view to Warsaw's natural system being further strengthened as regards its resistance to endogenous and exogenous factors, with the quality of life for inhabitants also raised, it is necessary for steps to be taken forthwith to improve the functioning of—and real protection offered to—the natural system, as well as the system by which air is exchanged and regenerated. It is necessary to point to the following targeted actions that may be regarded as of greatest importance. A spatially cohesive and effectively managed system of green space constituting an ecological network for Warsaw needs to be created, as linked up with the natural surroundings at regional level. The ecological network should be built out of biocentres linked together by ecological corridors that are spatially contiguous with Warsaw's "green ring". Such a ring would obligatorily have to be marked out in the physical development plan for Warsaw Metropolitan Area, as an area of permanent natural use. Besides the areas encompassed by the different forms of nature protection, the network should also include all of Warsaw's forest complexes, green areas of recreational functions (including larger patches of urban green space) and corridors allowing for the exchange and regeneration of air, albeit with the exclusion of corridors serving transport functions. Regard for Warsaw's ecological network and system of ventilation should be had in all of the city's planning and strategic documents, with precise defining of the boundaries of areas included within the network, first and foremost forests and urban green space of all different categories. Green areas associated with the proposed ecological network system and with the system of ventilation, as well as with local protection plans, should be included, and prohibitions on further building in such areas should be brought in.

The share accounted for by areas with tall greenery should be increased, including where these serve recreation-related functions. Areas of this kind should be distributed more evenly across the city and should link up with the system by which Warsaw is ventilated. There should be further progress with street trees offering natural shade for pavements, as well as shade for squares, greens and play areas as elements of great importance to the cooling of the city. Efforts also need to be made to enhance movement of air allowing better penetration of the heart of the built-up area, and also offering partial protection from insolation, especially on hot days or in the course of heatwaves. Urban-planning practice should make wider use of green roofs, terraces and ceilings and roofs, as well as green walls, most especially in housing-estate areas in which the share of biologically active land is now very low. Warsaw's woods and forests should be assured of good condition and protection against the building, and this should be justified in terms of the retention of their climatic potential, as well as the protection of biodiversity and places suitable for the recreation of inhabitants. Efforts should be made to increase the area of tall greenery, including woods in areas feeding into the ecological corridors, with this requiring close cooperation with local authorities in the suburban zone, as well as the establishment of a "green ring" around Warsaw as an ecological structure with a high degree of forest cover and spatial persistence. Efforts should also be made to ensure saturation of Warsaw Districts with the so-called blue infrastructure that is of great significance in cooling the city and ensuring places of recreation more "friendly" to the human organism, especially on hot or very hot days. Essential activity here includes the protection of all surface waters against disappearance and degradation, the reinstatement of certain former bodies of water and watercourses, and the construction of new ones. In densely built-up areas, in city-centre areas in particular, this greater saturation would be achieved by way of small architectural items (cascades, fountains, water curtains and so on). There will need to be a departure from an imprecisely defined spatial structure of the so-called natural system of the city that allows the building to take place, even where multifamily structures are concerned. Lax provisions allow for building in areas serving in the exchange and regeneration of air and in other areas valuable from the biological and recreational points of view, even if these are already qualified formally as elements of the aforementioned natural system. Spatial solution should be devised for the development of Warsaw (including city-proper) green space, forest and waters, with the aim being for these taken together to account for not less than 1/3 of the city area, and with guaranteed protection from any change of planning designation then being extended.

Summary and Conclusions

The threat to the functioning of the city system resulting from climate change requires a series of adaptive actions. In Poland, these are currently at the stage where strategic documents are being drawn up to adapt cities to the climate change presented in global and regional climate scenarios. However, it needs to be stressed that the strategic studies and planning documents that have come into being so far take only limited account of current knowledge on assumed climate change, or the nature of this change for the quality of human life. A notable positive exception would be the action being or to be taken to limit emissions of greenhouse gases.

The spatial studies done for Warsaw cited in this work and concerning possible changes of climate advocate a great deal of action intended to raise living standards of inhabitants, increase their security, lower the city's operating costs and optimise structural and spatial solutions where development is concerned. Assessing the variant solutions when it comes to adaptation, and coming up with a ranking of different associated actions, one must note that the key undertakings are those seeking to limit city temperature increases that lead to the emergence of so-called urban heat island (UHI) phenomena. While it is true that these cannot be precluded altogether, they can be modified in terms of intensity, if appropriate planning action is taken at city level and more locally. Appropriate planning can also facilitate inhabitants' adaptation to the phenomenon as and when it does arise.

The state of our knowledge to date confirms the significant influence land management can have on the intensity of UHI, when housing estates are compared from the point of view of their shares of biologically active land. Of slightly lesser importance is the indicator of the degree to which an area is built up—i.e. as a function of distance from city-centre areas. The conclusion is therefore that the extent of the biologically active area plays a key role as housing estates are designed—to limit the extent and intensity of the UHI affect as far as possible. Work done to date suggests that this effect can only be achieved where no less than 45–50% of a given area remains biologically active, and thus not built up. However, the determination of a precise threshold value requires further analyses in a greater number of model areas that take into consideration the form of construction and land cover, including also the share of the area not built up that is beyond the biologically active land as defined traditionally.

A further very important activity in terms of adaptation is flood protection in urbanised areas and notably the development of a flood-prevention scheme and system. There is obviously no way of introducing an entirely safe system of protection against flooding that is foolproof and can ensure 100% protection no matter how high the flood crest. However, systems of this kind can limit damage as far as possible, as and when flood events arise. It needs to be recalled here that flood damage goes beyond losses of property to include the negative consequences for the human psyche of going through one major flood event and/or fearing the arrival of another.

One aspect to flood-protection prophylaxis is the construction of specialist infrastructure including flood banks. However, embankments are ultimately just earthworks and ones that are perpetually in need of maintenance. Furthermore, their existence of necessity goes hand in hand with the pursuit of other hydrotechnical measures. In many Polish cities, and not least Warsaw, the approach denotes a raising of the level of banks along some sections if standards are to be increased to first class. But attention also clearly needs to be paid to the area between the flood banks, to ensure that this is sufficiently clear to allow for easy run-off of floodwaters, most especially those associated with cresting events capable of being generated by the torrential rain and cloudbursts that cause flash flooding.

Also referred to in this paper is the effort to address the threat of water shortages through further adaptational action helping to maintain the proper functioning of a city in circumstances of climate change. The concrete examples suggest that Warsaw is in a favourable position where the supply of water to its inhabitants is concerned, given that it has two independent sources in the Zegrze Reservoir and the River Vistula. However, no matter what its everyday situation as regards abstraction may be, each city ought to have an emergency water-supply system that can feed into water pipelines and supply citizens with drinking water in the circumstances of protracted drought. Thanks to a suitable location as regards artesian deposits of water from the Oligocene, Warsaw does in fact possess a resource that can always serve as an additional water source for city inhabitants.

In summing up the analysis carried out, it is necessary to make clear that the spatial development of cities entails many threats and problems only exacerbated by climate change, with the result that it becomes essential to take action to adapt to this more fully. Key activity will include efforts to limit further rises of temperature in city interiors and to optimise water management. In each case, the overriding objective must be the safety and security of city-dwellers from the point of view of their resistance to climate change. While an ageing society and worsening hydrological and thermal conditions seem an unfortunate combination, they can also serve as a stimulus to the development of the proposed spatial solutions, in line with which the human being is seen as the key object underpinning concrete and relevant action.

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Physiographic Influence on Rainfall Variability: A Case Study of Upper Ganga Basin

Uzma Parveen and S. Sreekesh

Abstract

Physiography of a region has a greater impact on climatic variables such as rainfall. The influence of physiography on rainfall has been analysed in various regions of the world, but in India, the number of such studies is quite inadequate keeping in mind its vast extent. Rainfall pattern shows large-scale regional variations. There is an absence of a comprehensive study dealing with the variability of rainfall in Ganga Basin. Therefore, in the present study, India Meteorological Department's rain gauge stations of the Ganga Basin have been selected for the analysis of rainfall variation. The rain gauge stations are selected in such a manner that they represent a wide range of physiographic differences that is from mountains to plain. The general elevation of the selected stations varies from 100 to 2000 m. The analysis found that there is high variability in rainfall distribution and there is an increase in rainfall with altitude. Studies of this kind provide an insight to understand the behaviour of climatic variables in different physiographic regions and are very helpful to identify the areas that are more vulnerable to climate change.

Keywords

Rainfall variability · Mann–Kendall test · Sen's slope · Physiography

Introduction

In the last few decades, there has been a spurt in the concerns on climate change and variability across the world. It turned into a crucial global issue because of the fact that the very existence and sustainability of life on the Earth is threatened by this global problem. It is a well-known

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fact that climate is a dynamic phenomenon and so are its components. All the climatic parameters, particularly precipitation, vary greatly over space and time. Rainfall, as a climate parameter, has been studied extensively because changes in rainfall pattern are an indication of climate variability or change.

The global climate as well as Asian monsoon system has been considered to be governed by the Himalaya and Tibetan Plateau (Prell and Kutzbach 1992). Thus, the physiography is a prime determinant of climatic parameters (Dobrowski et al. 2009) and this is one of the reasons why the quantity of annual rainfall received in India varies from below 13 cm in Western Rajasthan to about 1141 cm in Mawsynram. The local physiographic condition has great bearing on continuous variability in rainfall distribution than any other climatic parameter. Consequently, the pattern of rainfall has depicted great variation from one to another region and mountains have attracted special attention for our sustainable future (Diaz et al. 2003). A decreasing trend of rainfall has appeared to persist in many parts of the world, i.e., over Canada (Gan 1998), Italy (Ventura et al. 2002), Russia, China and Thailand (Dore 2005). On the contrary, increasing trend of rainfall has been found out over North Carolina (Boyles and Raman 2003) and Spain (Mosmann et al. 2004). In India, particularly, no significant trend of annual rainfall has been observed (Parthasarathy and Dhar 1976; Parthasarathy and Mooley 1978). Some studies, however, have reported significant regional variability of monsoonal and annual rainfall over India (Hastenrath and Rosen 1983; Vines 1986; Krishnamurthy and Shukla 2000; Varikoden et al. 2013) where some regions are showing increasing trend while others are reporting declining trend (Srivastava et al. 1992; Singh et al. 2005).

At regional scale also rainfall has shown varying trends. An increasing trend of rainfall has observed over northwest India (Kumar et al. 1992), Delhi (Rao et al. 2004), and in the river basins of Indus, Ganga, Brahmaputra, Krishna and Cauvery (Singh et al. 2005). Rising trend of annual rainfall with least variability during monsoon season was observed in the basins of North India (Singh et al. 2007), whereas decreasing rainfall trend has been reported over Mahi, Tapti, Sabarmati and Mahanadi river basins (Singh et al. 2005). Kothyari et al. (1997) have found decreasing rainfall trend over the Ganga Basin, whereas Singh and Sontakke (2002) have shown an increasing trend of rainfall over western Gangetic plain and insignificant decreasing trend in the central part. Rainfall has declined in the last century over the Himalayas located in the state of Uttarakhand (Basistha et al. 2009).

It is important to note here that in none of the studies, influence of physiography on rainfall has been taken into account. However, in one of the studies, latitudinal variability of precipitation has been analysed for Pakistan between 1951 and 2010 (Hanif et al. 2013). The present study aimed to analyse the variability in distribution of rainfall and rainy days and assess whether the variability also changes with physiography.

Materials and Methods

The rainfall (in mm) and rainy days have been collected from monthly rainfall series database (digital) provided by India Meteorological Department (IMD) for the period 1961–2010. Climatological normal for rainfall as well as for rainy days has been obtained from Climatological Table (IMD 2010). The area of study has been divided into two major physiographic divisions, mountainous and plain. A total of 17 rain gauge stations have been included in the present study of which 6 are lying in the mountainous region while remaining are located in plain area (Fig. 1).

Coefficient of variation (CV in %) has been used to assess variability of seasonal rainfall and rainy days. Anomaly represents the departure of weather parameters from their normal value either in positive or in negative direction during a particular year, month, or season (Rao 1999; Dash et al. 2007; Jaiswal 2009; Attri and Tyagi 2010). In this study, climatic normal for rainfall and rainy days has been collected from Climatological Table (IMD 2010). For the stations not included in this table, normal has been calculated

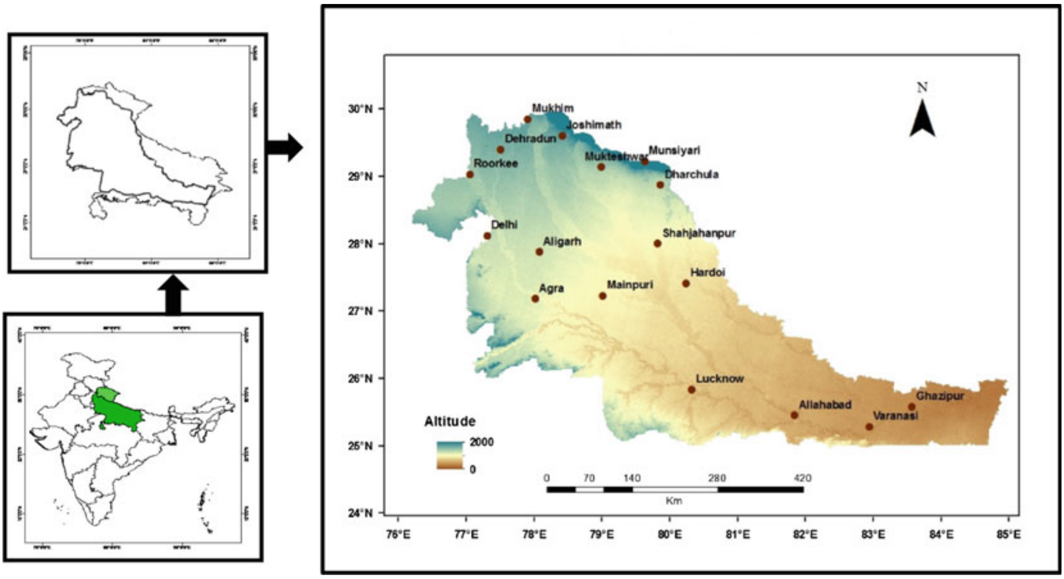

Fig. 1 Location of study area, altitudinal variation within basin and distribution of rain gauge stations

by averaging 30-year rainfall values. Thereafter, percentage departure of rainfall and rainy days has been calculated as

$$\text{Percentage departure} = \text{Actual rainfall} - \text{Normal Rainfall}/\text{Normal Rainfall} * 100$$

Departure above 19% of normal has been considered as a significant positive departure, while below 19% of normal is taken as a significant negative departure. Data for rainy days is incomplete for Munsiyari, and thus, departure of rainy days has not been analysed for Munsiyari.

For the analysis of trend in data series, nonparametric Mann–Kendall (M-K) trend test has been used. Mann–Kendall trend test is one of the most extensively utilized methods to study the trend of meteorological data.

$$Z = \begin{cases} s - 1/(\sqrt{VAR}(S) & \text{if } S > 0 \\ 0 & \text{if } S = 0 \\ s + 1/(\sqrt{VAR(S)} & \text{if } S < 0 \end{cases}$$

where Z is the normalized test statistics and S is Mann–Kendall test variance.

One of the most important characteristics of this test is that no assumption has to be made regarding the normality of data (Dash and Mamgain 2011). M-K trend test examines the null hypothesis of no trend in opposition to the alternative hypothesis of the increasing or decreasing trend (Kumar et al. 2010). The test is very suitable to analyse trend in data over a period as it does not require any assumption regarding statistical distribution of data and can be used for data sets that include irregular sampling intervals and missing data (Mustapha 2013).

Sen's slope estimator is a simple nonparametric test developed by Sen and presented by Gilbert to estimate the true slope of M-K trend test (Mustapha 2013). It computes the magnitude of any significant trend found in the M-K test. Sen's slope is not influenced by single data errors or outliers. Sen's slope can be calculated as $Q = x_j - x_k/j{-}kj/j$

where Q is the value of Sen's slope estimator; x_j and x_k are data values at time j and k.

Area of Study

This study has been carried out for the rain gauge stations located in the upper Ganga and parts of middle Gangetic plain (Fig. 1). The Ganga Basin also provides an ideal location to serve the

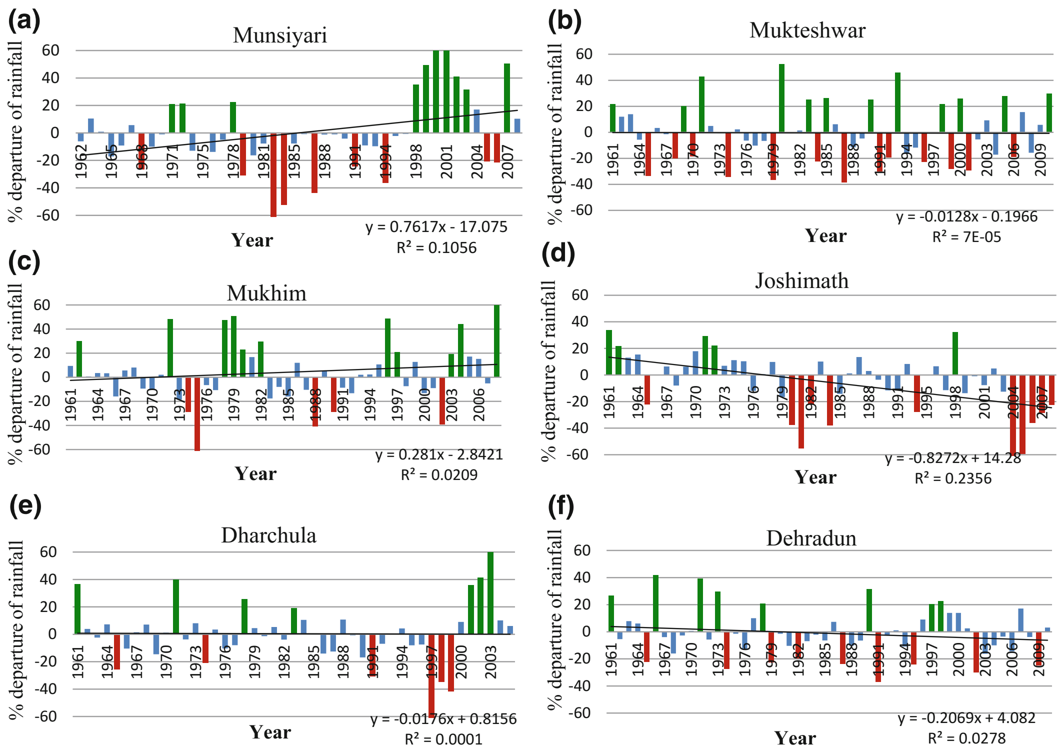

Fig. 2 Percentage departure of rainfall in mountainous region. <19% negative departure of rainfall from normal is shown by *red bars* and >19% positive departure of rainfall from normal by *green bars*. Rainfall between above limits is shown by *blue bars*

objective of the study due to its varying physiographic setting. The analysis has been done for selected rain gauge stations that constitute upper and parts of middle Ganga Basin. The study area has been divided into mountainous and plain regions (Fig. 2). The stations located in mountainous region are Munsiyari, Mukteshwar, Mukhim, Joshimath, Dharchula and Dehradun, while those of plain region are Roorkee, Delhi, Shahjahanpur, Aligarh, Agra, Mainpuri, Hardoi, Lucknow, Allahabad, Varanasi and Ghazipur. The altitude of these stations ranges from 70 m in plain area to above 2000 m in mountainous area (Table 1). This is important to analyse the influence of altitude on varying patterns of rainfall and rainy days. These stations fulfil the requirements of the study as they represent major physiographic divisions of Ganga Basin.

Results and Discussion

Variability of Seasonal Rainfall

In the mountainous region, rainfall has recorded to be highly variable during post-monsoon season (Table 2). Here, Mukteshwar and Dehradun stations have maximum variability of rainfall during post-monsoon season as compared to the other stations located in high altitude region. Apart from these, at Mukhim and Joshimath also rainfall has been variable during post-monsoon season. However, among all stations Munsiyari experienced least variable rainfall during post-monsoon season. During monsoon season, rainfall has remained fairly persistent at all the stations.

Table 1 Rain gauge stations selected for the study

Sr. no.	Name of the station	Period	No. of years	Average elevation (m)	Geographic location
1.	Munsiyari	1961–2008	48	2298	30° N, 78° E
2.	Mukteshwar	1961–2010	50	2286	29° N, 79° E
3.	Mukhim	1961–2008	48	1945	30° N, 78° E
4.	Joshimath	1961–2008	48	1168	30° N, 79° E
5.	Dharchula	1961–2010	50	915	29° N, 80° E
6.	Dehradun	1961–2010	50	636	30° N, 78° E
7.	Roorkee	1961–2010	50	268	29° N, 77° E
8.	Delhi	1961–2009	49	237	28° N, 77° E
9.	Shahjahanpur	1977–2010	23	194	27° N, 79° E
10.	Aligarh	1961–2010	50	178	27° N, 78° E
11.	Agra	1961–2008	48	171	27° N, 78° E
12.	Mainpuri	1961–2005	45	153	27° N, 79° E
13.	Hardoi	1961–2010	50	134	27° N, 80° E
14.	Lucknow	1961–2010	50	120	26° N, 80° E
15.	Allahabad	1976–2010	24	98	25° N, 81° E
16.	Varanasi	1961–2010	50	81	25° N, 83° E
17.	Ghazipur	1979–2010	21	70	25° N, 83° E

Table 2 variability of seasonal rainfall (CV in %)

Stations	Pre-monsoon	Monsoon	Post-monsoon	Winter
Munsiyari	**65.6**	30.9	**66.5**	**61.8**
Mukteshwar	47.4	26.8	**107.2**	58.9
Mukhim	58.7	31.7	**85.1**	54.3
Joshimath	44.8	29.0	**82.0**	49.4
Dharchula	49.8	23.4	**78.3**	**60.1**
Dehradun	**61.6**	20.8	**89.5**	54.2
Roorkee	**79.5**	36.8	**81.8**	**61.3**
Delhi	**101.5**	32.3	**111.0**	**75.0**
Shahjahanpur	**123.5**	27.1	**127.9**	**81.8**
Aligarh	**84.5**	32.3	**95.2**	**82.3**
Agra	**78.4**	33.1	**105.1**	**84.4**
Mainpuri	**93.2**	31.7	**105.6**	**105.5**
Hardoi	**91.2**	28.5	**155.5**	**98.3**
Lucknow	**81.5**	35.7	**125.2**	**88.0**
Allahabad	**67.2**	30.5	**81.6**	**76.9**
Varanasi	**84.8**	25.0	**95.7**	**77.0**
Ghazipur	**76.8**	20.1	**88.4**	**80.2**

Note Red colour is showing coefficient of variation >60%, and black colour is showing coefficient of variation <60%. Stations located at higher elevation (>500 m) are shown by blue colour, whereas stations located at lower elevation (<500 m) by brown colour

Table 3 Seasonal variability of rainy days (CV in %)

Stations	Pre-monsoon	Monsoon	Post-monsoon	Winter
Munsiyari	51.1	20.3	55.5	57.8
Mukteshwar	40.1	16.1	**60.4**	48.9
Mukhim	42.3	25.1	**70.6**	41.1
Joshimath	34.2	22.2	53.6	41.1
Dharchula	37.6	11.8	51.1	45.0
Dehradun	51.4	14.0	**60.9**	39.5
Roorkee	59.9	32.7	**69.8**	57.8
Delhi	59.4	25.6	**97.8**	**79.7**
Shahjahanpur	**74.2**	27.6	**73.7**	**74.2**
Aligarh	**67.0**	25.4	**81.9**	**70.0**
Agra	**71.0**	25.8	**112.5**	**83.8**
Mainpuri	**79.5**	24.1	**97.3**	**80.1**
Hardoi	**67.1**	22.2	**92.0**	**78.5**
Lucknow	**66.1**	20.0	**78.0**	**72.3**
Allahabad	56.7	22.2	**68.5**	**76.7**
Varanasi	**75.8**	16.1	58.1	**67.3**
Ghazipur	**74.4**	18.2	**72.5**	**69.8**

Note Red colour is showing coefficient of variation >60%, and black colour is showing coefficient of variation <60%. Stations located at higher elevation (>500 m) are shown by blue colour, whereas stations located at lower elevation (<500 m) by brown colour

In plain, similarly, rainfall has been highly variable during post-monsoon season. The variability is higher (>100% except in middle Ganga Basin) for the stations in the plains than those in mountains. It is important to note that unlike high altitudinal areas, in plain region during winter season also rainfall has exhibited great variability. Therefore, it can be stated that while descending from higher elevation to lower elevation, the variability of seasonal rainfall has increased.

Seasonal Variability of Rainy Days

It is evident from Table 3 that similar to rainfall, rainy days have shown less variability during monsoon season, whereas during post-monsoon season rainy days have remained highly variable. Among mountainous stations, during post-monsoon, Mukhim has received maximum variability of rainy days followed by Dehradun and Mukteshwar. At Munsiyari, Joshimath and Dharchula, in contrast, rainy days have shown the least variable pattern during all the seasons. During monsoon season, the variability of rainy days has been considerably low at all the stations and irrespective of the altitude.

In plain region during pre-monsoon, post-monsoon as well as winter season, rainy days have varied significantly. However, maximum variability has appeared again during post-monsoon season followed by winter season. Roorkee is exhibiting least variable pattern of rainy days where rainy days varied only during post-monsoon season. This has been followed by Delhi and Varanasi.

Departure of Rainfall from Normal

In Mountainous Region

The analysis of departure of rainfall has shown varied patterns among the stations analysed here.

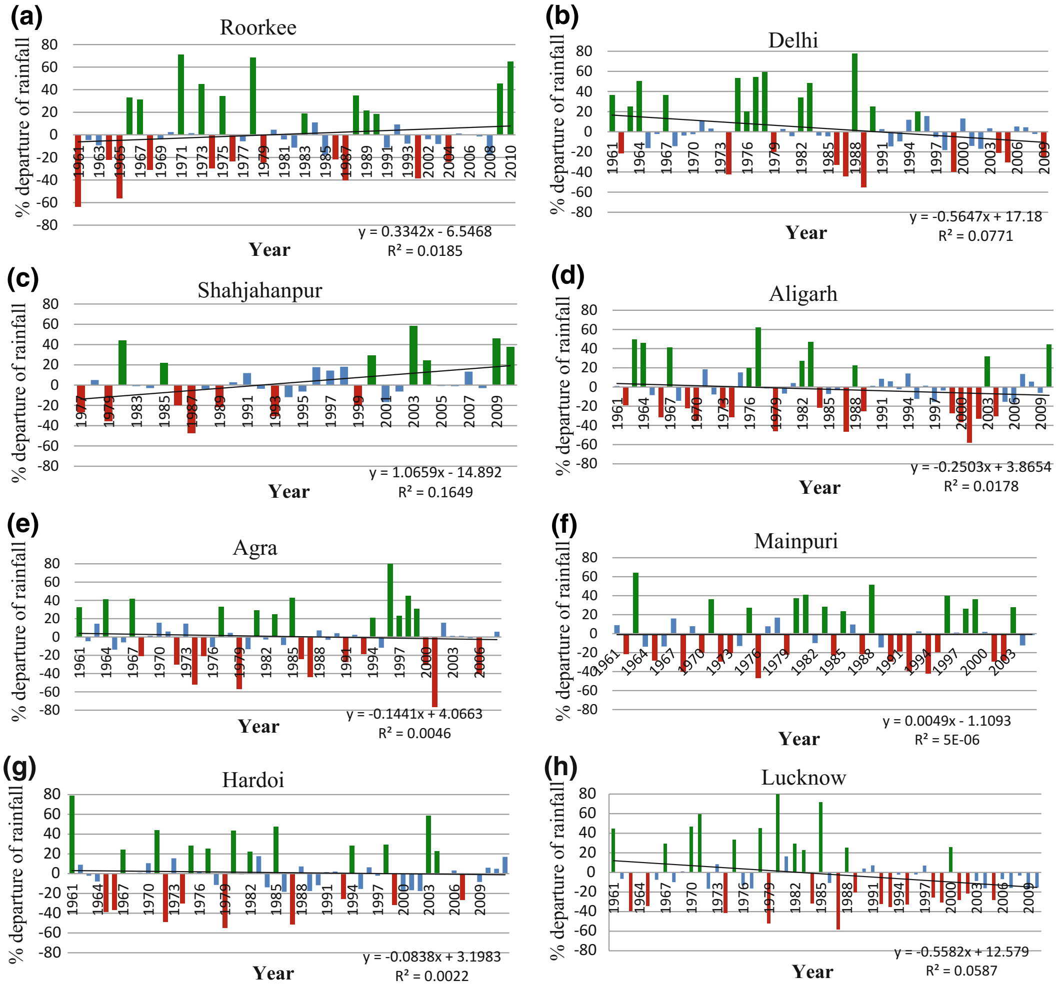

Fig. 3 Percentage departure of rainfall in plain region. <19% negative departure of rainfall from normal is shown by *red bars* and >19% positive departure of rainfall from normal by *green bars*. Rainfall close to normal is shown by *blue bars*

At Munsiyari, Mukhim and Dharchula, positive departure of rainfall has increased during the recent period of study (Fig. 2a, c, e). In contrast to this, at Joshimath, rainfall has exhibited negative departure after the year 2000 (Fig. 2d).

Munsiyari, Mukhim and Dharchula (Fig. 2), stations in mountainous area experienced positive departure of rainfall during the period of study. Most of these positive departures occurred during the latter period of the study. In contrast to this, at Joshimath, rainfall has exhibited negative departure, especially after the year 2000. It is observed that in most of the stations rainfall has deviated more significantly during later years. At Munsiyari and Mukhim, a positive departure of rainfall has become more prominent after the late nineties (Fig. 2a, c). At Dharchula, similar pattern of rainfall departure has appeared 2000 onward (Fig. 2e). At Joshimath, however, negative departure of rainfall has occurred during the later period of study (Fig. 2d).

In Plain Region

Rainfall has remained highly variable in plain region throughout the study period (Fig. 3). It has been, however, observed that departure of

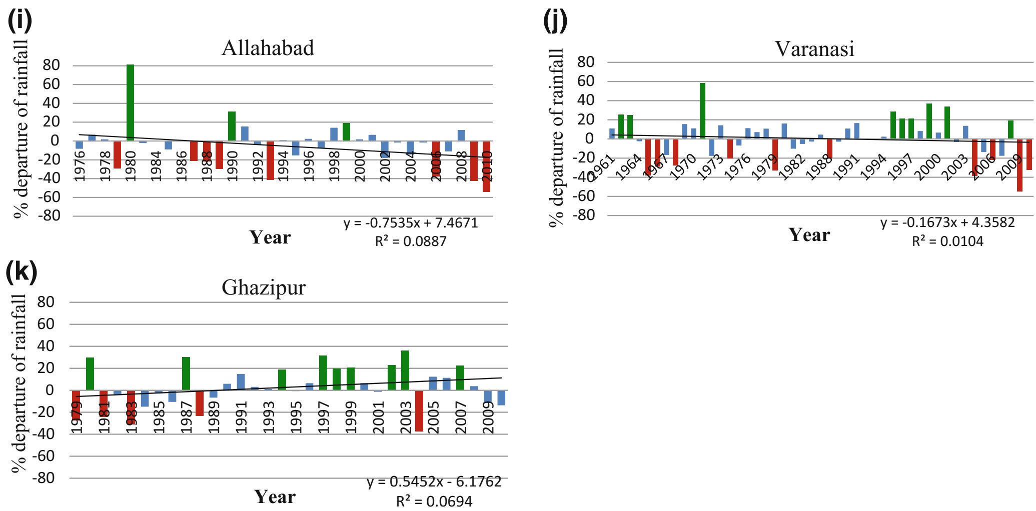

Fig. 3 (continued)

rainfall has been comparatively high in the western part of the plain region (at relatively higher altitude) as the number of years receiving positive (>19%) or negative (< −19%) departure of rainfall has been more. Contrary to this, at the stations located at relatively lower altitude, the number of years showing departure of rainfall has declined.

It has also appeared that at some stations, i.e., Delhi (Fig. 3b), Agra (Fig. 3e), Hardoi (Fig. 3g) and Lucknow (Fig. 3h), rainfall has mostly remained close to normal beyond 2000. However, at Shahjahanpur (Fig. 3c), positive departure is taking place during recent years of study. In opposition at Allahabad (Fig. 3i) and Varanasi (Fig. 3j), negative departure of rainfall is occurring.

The departure of rainfall, especially positive, has been high at the stations located at relatively higher altitude, whereas at the stations located at lower altitude deviation of rainfall from normal has been low. In the plain region, most of the stations experienced negative departure of rainfall, especially during the later part of study period. Thus, in plain region, rainfall has varied significantly from its normal at most of the stations, whereas in mountainous region departure of rainfall has been lesser in comparison with the plain region.

Departure of Rainy Days

In Mountainous Region

Mukteshwar (Fig. 4a), Mukhim (Fig. 4b), Joshimath (Fig. 4d), Dharchula (Fig. 4e) and Dehradun (Fig. 4f) have negative departure of rainy days. The rate of departure varied across stations. Data on rainy days are intermittently missing for Munsiyari, and thus, the results are not consistent.

Therefore, from the above analysis, it can be stated that in mountainous region, rainy days have been either deviated in negative direction in majority of the cases indicating a decline in rainy days or remained close to the normal indicating insignificant change in rainy days. However, such decline in rainy days has not resulted in a significant reduction in rainfall amount. This point towards in intensification of rainfall in mountainous region.

In Plain Region

In comparison with mountainous region, the number of rainy days has varied greatly from normal in the plain region. At Shahjahanpur (Fig. 5c), Hardoi (Fig. 5g) and Lucknow (Fig. 5h), the number of rainy days has appeared to close to normal during recent period. At Aligarh (Fig. 5d) and Varanasi (Fig. 5j), rainy days

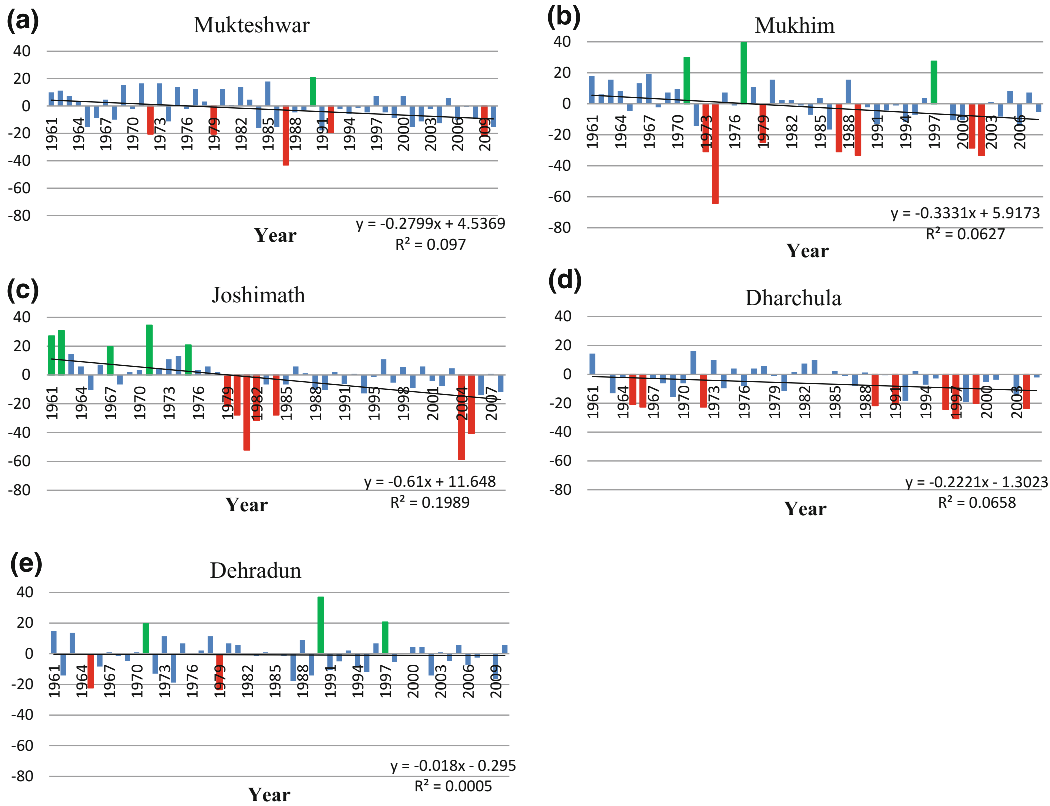

Fig. 4 Percentage departure of rainy days in mountainous region. <19% negative departure of rainfall from normal is shown by *red bars* and >19% positive departure of rainfall from normal by *green bars*. Rainfall close to normal is shown by *blue bars*

have remained persistent throughout the period of study. In Roorkee (Fig. 5a), Delhi (Fig. 6b) and Ghazipur (Fig. 5k), the rainy days have increased over the study period.

Thus, it has become obvious that in plain region, rainy days have deviated from normal in most of the years. However, the number of years with positive departure has appeared to be more as compared to the years during which negative departure has been reported. It can be concluded (Fig. 6) that moving from relatively high elevation to lower elevation departure of rainy days has decreased and they have mostly found to be close to normal in plain areas.

It becomes obvious that the number of years with the significant departure of rainy days is less as compared to departure of rainfall in the mountainous region. In plain region, however, years with the significant departure of rainfall as well as rainy days have been higher (Table 4). There is no coincidence among the stations neither in case of positive departure nor in the case of negative departure of rainy days. It indicates that there is no regional pattern in departure of rainy days from the normal.

Trend of Rainfall

In mountainous region during 1961–2010, rainfall has revealed an increasing trend at Munsiyari and Mukhim (though not statistically significant). The increase in the magnitude of rainfall has been 1.49 mm/year and 0.88 mm/year, respectively, for these stations. Contrary to this, at all the other stations decreasing trend of rainfall has

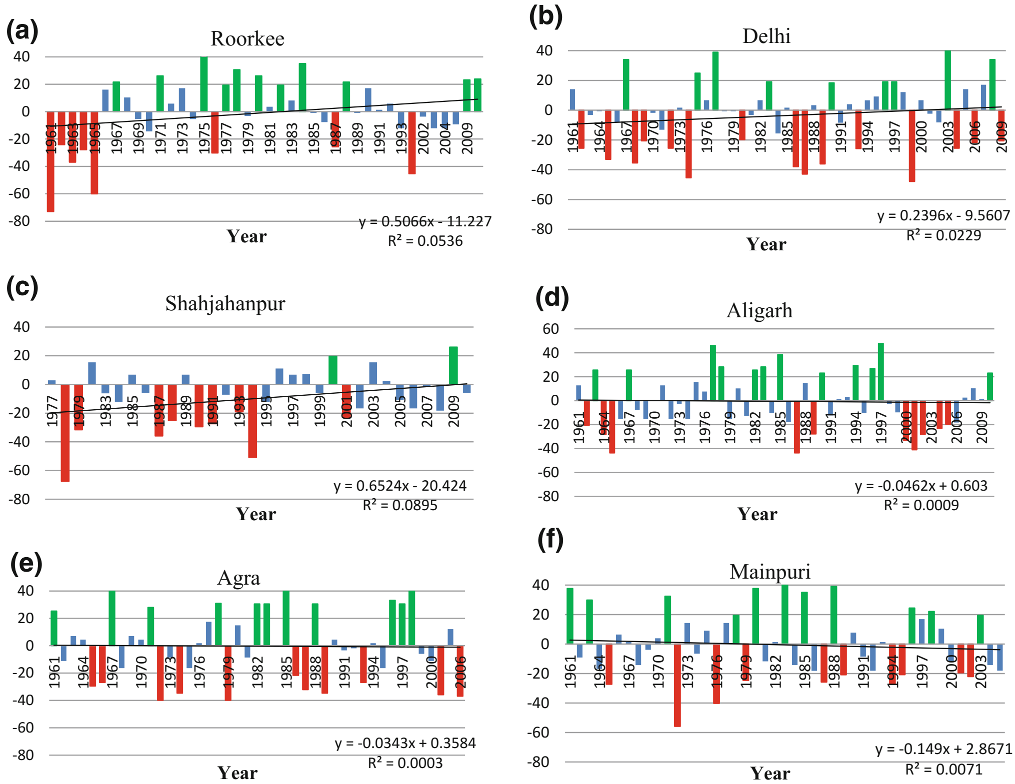

Fig. 5 Percentage departure of rainy days in plain region. <19% negative departure of rainfall from normal is shown by *red bars* and >19% positive departure of rainfall from normal by *green bars*. Rainfall close to normal is shown by *blue bars*

appeared as denoted by *Z* value. However, the decreasing trend of rainfall is statistically significant only for Joshimath. For Joshimath, level of significance is also very high (***) as null hypothesis of no trend has been rejected at 0.001 level of significance and the magnitude of rainfall decline has been −3.58 mm/year.

In plain region, increasing trend of rainfall has appeared for Shahjahanpur and Ghazipur (Table 5). For Shahjahanpur, null hypothesis of no trend has been rejected at 0.05 level of significance, whereas for Ghazipur null hypothesis has been rejected at 0.01 level of significance, both indicating an increase in rainfall. The increase in the magnitude of rainfall has been 2.22 mm/year at Shahjahanpur and 2.71 mm/year at Ghazipur. Contrary to this, as Z value signifies, at other stations decreasing trend of rainfall has appeared during 1961–2010, but it is statistically insignificant. However, at Delhi, decreasing trend of annual rainfall is statistically significant at 0.1 level of significance. Here, decrease in the magnitude of rainfall has been −1.80 mm/year. At all other stations located in the plain region, rainfall has remained consistent during 1961–2010.

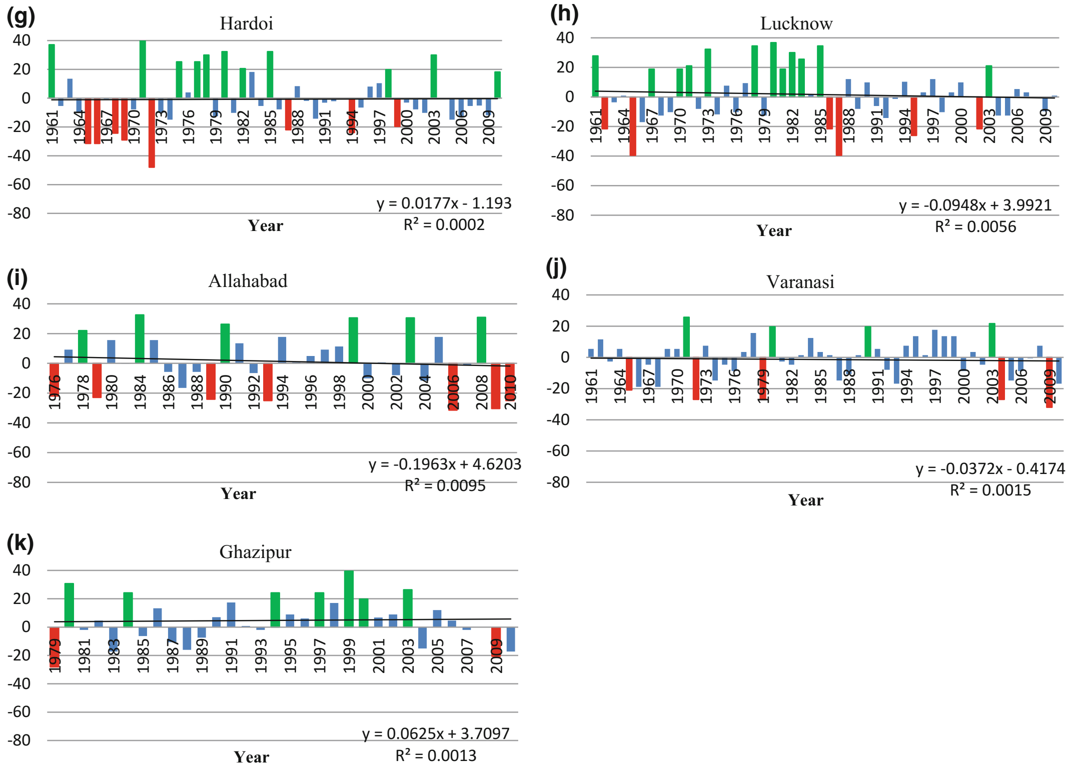

Fig. 5 (continued)

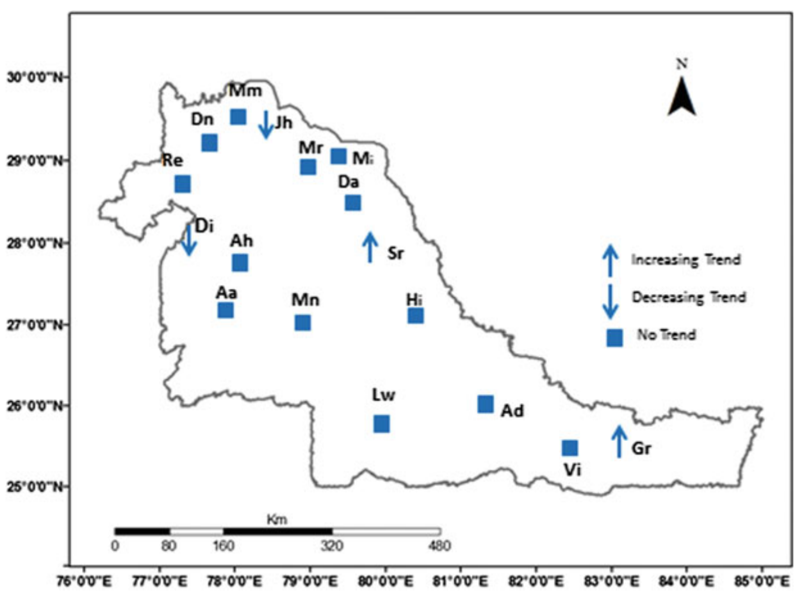

Fig. 6 Spatial distribution of trend of rainfall during 1961–2010. Note: *Mi* Munsiyari, *Mr* Mukteshwar, *Mm* Mukhim, *Jh* Joshimath, *Da* Dharchula, *Dn* Dehradun, *Re* Roorkee, *Di* Delhi, *Sr* Shahjahanpur, *Ah* Aligarh, *Aa* Agra, *Mn* Mainpuri, *Hi* Hardoi, *Lw* Lucknow, *Ad* Allahabad, *Vi* Varanasi, *Gr* Ghazipur

Table 4 Summary table of departure of rainfall and rainy days

Station	No of Years	Positive departure of rainfall	Negative departure of rainfall	Positive departure of rainy days	Negative departure of rainy days
Munsiyari	48	11	9	-	-
Mukteshwar	50	12	13	1	5
Mukhim	48	11	5	3	7
Joshimath	48	5	11	5	7
Dharchula	50	7	6	0	9
Dehradun	50	8	9	3	2
Roorkee	50	12	11	11	8
Delhi	49	13	10	9	15
Shahjahanpur	23	7	7	2	9
Aligarh	50	10	15	12	10
Agra	48	12	12	11	11
Mainpuri	45	12	17	11	10
Hardoi	50	12	9	11	8
Lucknow	50	12	14	12	6
Allahabad	24	3	8	6	7
Varanasi	50	9	10	4	5
Ghazipur	21	9	5	7	2

Note Stations located at higher elevation (>500 m) are shown by blue colour, whereas stations located at lower elevation (<500 m) by brown colour

Table 5 Trend in rainfall during 1961–2010

Stations	Mann-Kendall trend	Sen's slope estimate		
	Test Z	Q	Qmin95	Qmax95
Munsiyari	1.49	13.748	-3.569	32.016
Mukteshwar	-0.08	-0.450	-7.027	5.270
Mukhim	0.88	2.879	-4.647	11.257
Joshimath	-3.58***	-8.973	-12.843	-4.194
Dharchula	-0.03	-0.295	-11.599	9.487
Dehradun	-0.89	-3.148	-11.680	4.226
Roorkee	-0.76	-2.215	-8.928	4.025
Delhi	-1.80 +	-4.432	-9.011	0.310
Shahjahanpur	2.22*	10.806	0.837	19.755
Aligarh	-0.69	-1.557	-6.326	2.901
Agra	-0.40	-1.221	-5.411	3.322
Mainpuri	0.07	0.153	-4.600	5.057
Hardoi	-0.50	-1.180	-6.317	3.881
Lucknow	-1.46	-4.815	-10.836	1.629
Allahabad	-1.45	-4.508	-13.471	1.864
Varanasi	-0.28	-0.407	-6.203	5.164
Ghazipur	2.71**	11.560	3.392	18.607

Note ***if trend at $\alpha = 0.001$ level of significance. **if trend at $\alpha = 0.01$ level of significance. *if trend at $\alpha = 0.05$ level of significance. + if trend at $\alpha = 0.1$ level of significance. Stations located at higher elevation (>500 m) are shown by blue colour, whereas stations located at lower elevation (<500 m) by brown colour

Table 6 Trend in rainy days during 1961–2010

Stations	Mann-Kendall trend	Sen's slope estimate		
	Test Z	Q	Qmin95	Qmax95
Munsiyari	0.26	0.134	-1.248	1.192
Mukteshwar	-2.62**	-0.314	-0.580	-0.098
Mukhim	-2.79**	-0.459	-0.722	-0.146
Joshimath	-3.93***	-0.824	-1.333	-0.426
Dharchula	-2.10*	-0.463	-0.900	-0.025
Dehradun	-1.50	-0.147	-0.391	0.049
Roorkee	-0.31	-0.062	-0.417	0.500
Delhi	-0.28	-0.027	-0.247	0.200
Shahjahanpur	1.01	0.283	-0.269	0.750
Aligarh	-1.38	-0.139	-0.371	0.061
Agra	-0.85	-0.138	-0.486	0.167
Mainpuri	-1.11	-0.157	-0.400	0.101
Hardoi	-0.90	-0.088	-0.400	0.114
Lucknow	-0.92	-0.100	-0.320	0.108
Allahabad	-0.20	-0.061	-0.600	0.627
Varanasi	-0.83	-0.063	-0.234	0.098
Ghazipur	-0.16	-0.026	-0.522	0.500

Note ***if trend at α = 0.001 level of significance. **if trend at α = 0.01 level of significance. *if trend at α = 0.05 level of significance. + if trend at α = 0.1 level of significance. Stations located at higher elevation (>500 m) are shown by blue colour, whereas stations located at lower elevation (<500 m) by brown colour

Trend of Rainy Days

Trend analysis of rainy days during 1961–2010 has indicated increasing trend only at Munsiyari (Table 6). However, this is not statistically significant. The increase in the magnitude of rainy days has been 0.26 days/year. Contrary to this, it appears that rainy days are decreasing at other stations. The decreasing trend has been noticeable and statistically significant at Mukteshwar, Mukhim, Joshimath and Dharchula. At Joshimath, the decreasing trend has been more significant at 0.001 significant level. At Mukteshwar and Mukhim, null hypothesis has been rejected at 0.01 level of significance, whereas for Dharchula at 0.05 level of significance (Table 6).

At most of the stations located in the plain region, decreasing trend of rainy days has emerged as signified by Z test statistics. However, at none of the stations, decreasing trend has been statistically significant (Table 6). At all the stations, null hypothesis of no trend has been accepted that signifies that no significant increase or decrease in the number of rainy days has occurred in the plain region (Fig. 7). However, it is to be noted that there is a tendency to decline the rainy days in the plain region. It may negatively impact the amount of rainfall received annually in the region and thus the water availability conditions in this region. It is also to be noted that the in mountainous region, stations are showing declining trend in rainy days while in plain there is no specific trend.

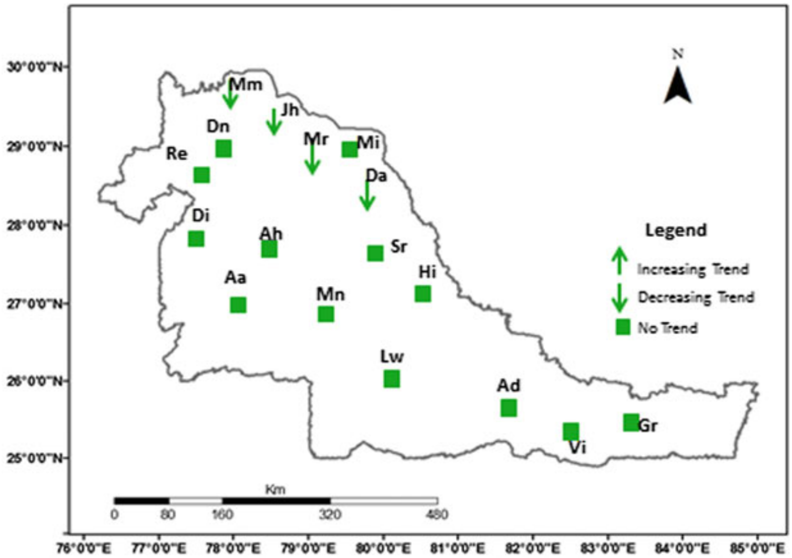

Fig. 7 Spatial distribution of trend of rainy days during 1961–2010. Note: *Mi* Munsiyari, *Mr* Mukteshwar, *Mm* Mukhim, *Jh* Joshimath, *Da* Dharchula, *Dn* Dehradun, *Re* Roorkee, *Di* Delhi, *Sr* Shahjahanpur, *Ah* Aligarh, *Aa* Agra, *Mn* Mainpuri, *Hi* Hardoi, *Lw* Lucknow, *Ad* Allahabad, *Vi* Varanasi, *Gr* Ghazipur

Conclusion

The above analysis showed that rainfall during all the seasons has declined as one moves from mountainous to plain region. The variability of seasonal rainfall is comparatively high in plain region. During monsoon season, rainfall was the least variable over both the physiographic divisions. This means that water availability in the upper Ganga Basin has not been subjected to any change since over 70% annual rainfall is received during this season. Contrary to this, high variability of rainfall has been observed during post-monsoon season followed by pre-monsoon season. In plain areas during winters also rainfall has shown high variability. Therefore, it can be concluded that the pattern of rainfall has changed considerably across the altitude in the region. In Ganga Basin, the variability of seasonal rainfall is high in plain areas and a decreasing pattern of rainfall is taking place. The number of rainy days, similar to rainfall, has declined moving from mountainous to plain region during each season. In high altitude region, negative departure of rainy days has persisted at most of the stations. However, in plain region, negative departure has been observed only at the stations located at comparatively higher altitude, whereas at the stations located at lower altitude rainy days have mostly recorded close to normal.

Seasonal variability of rainy days has been low in mountainous region during the period of study (1961–2010). In plain region, most of the stations have shown decreasing trend of rainy days, but it has not been statistically significant at any of the stations. Thus, no significant trend of rainy days has emerged in plain region even if the monthly and seasonal variability of rainy days has been high. On the basis of above analysis, it can be concluded that along with rainfall, the number of rainy days is also decreasing in upper Ganga Basin. However, the rainy days showed a declining trend while the amount of rainfall remained near to normal or marginal decline, indicating that the intensity of rainfall is increasing in mountainous region. This may, in the long term, affect water availability conditions in the Ganga Basin, especially its upper region.

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Water Deficit Estimation Under Climate Change and Irrigation Conditions in the Fergana Valley, Central Asia

Elena Milanova, Aleksandra Nikanorova, Andrei Kirilenko and Nikolay Dronin

Abstract

We evaluated changes in irrigation water deficit in the Fergana Valley, Central Asia under different scenarios of climate change and water management. The Fergana Valley is located within the Syr Darya river basin and is shared between Uzbekistan, Kyrgyzstan, and Tajikistan. The main driver of economic activity in the Valley is cotton farming, which consumes large volumes of water. Growing population drives irrigation water demand with plans to modernize the irrigation system increasing the irrigated areas by 10–15% underway. However, climate change may alter projected water demand increase in the Valley. We estimated the climate-related changes in irrigational water demand in the Fergana Valley in 2020s, 2050s, and 2080s using future weather patterns generated with five global circulation models (GCMs) run under the A1FI, A2, and B1SRES scenarios. Considerably higher temperatures and a moderate change in precipitation lead to increasing potential evapotranspiration (PET), which nearly doubles irrigation water demand by the 2080s. In turn, the area under persistent water deficits increases from current 12% to 18.3% by 2020s, 27% by 2050s, and to 38.2% by 2080s. That is driving demand for a scientifically substantiated scheme of irrigation keeping in mind the quality of soils and groundwater table, correction of water consumption norms for different crops, and change of crop composition in favor of the winter horticulture plantations and cereals. On a long run, a radical modernization of the irrigation system will be needed to cope with climate change in the Fergana Valley.

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Keywords
Climate change · Irrigation · Agriculture · Central Asia · Fergana Valley · Water demand · Cotton production

Introduction

The Aral Sea basin (Fig. 1) is a zone of a widespread water-related ecological crisis. While a sustainable agriculture on irrigated lands has probably existed for thousands years in the region, the promotion of large-scale cotton production on newly irrigated lands in the 1960s–1980s has resulted in a radical drop of the Aral Sea level. As a result of increased water withdrawal from two major rivers feeding the Aral Sea, Syr Darya provided no water discharge to the Aral Sea in 1974–1986, and Amu Darya discharge was very low to none in 1982–1983, 1985–1986, and in 1989 (Izrayel' and Anokhin 1991). While the recent shift from cotton to lesser water intensive food crops increased the annual water discharge to the Aral Sea to 14 km^3, a complete restoration of the Aral Sea requires about 54 km^3 annual flow (Severskiy 2004).

Two major tributaries, Amu Darya and Syr Darya rivers, are the principle water sources in the region. A large reduction of agricultural water withdrawal up to 30 km^3 (Micklin 2006) may be possible through modernization of outdated water management and irrigation infrastructure in all post-Soviet countries of the region. However, these optimistic projections consider water management under the current climate. Climate change may further increase water demands, affecting agriculture, industry, and population, intensifying transboundary conflicts over water. As a result, the increasing irrigation water availability driven by innovated infrastructure and management can be overwhelmed by increasing agricultural water demand driven by warmer and dryer weather patterns.

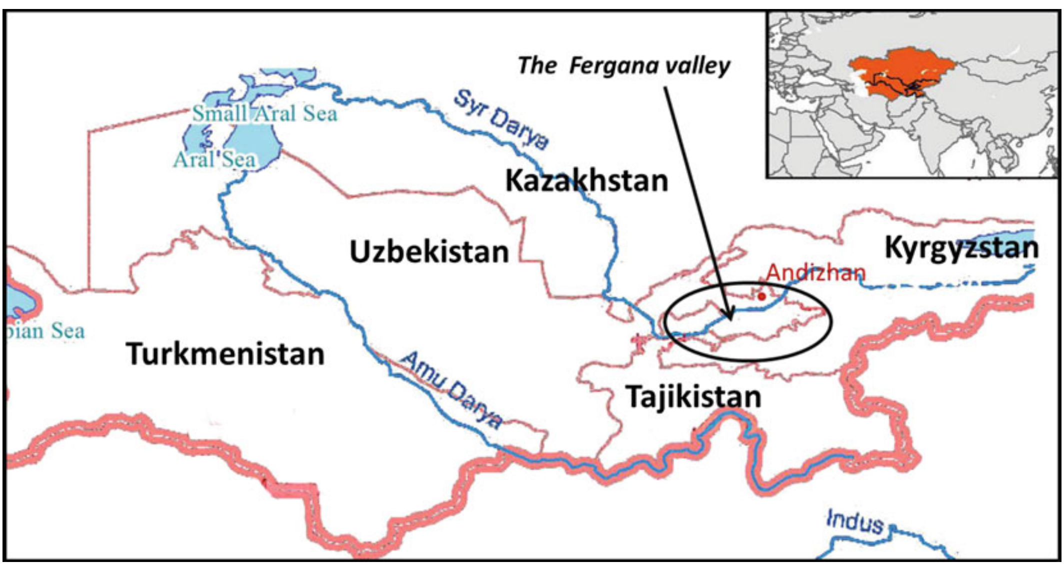

Fig. 1 Aral Sea Basin countries

The Fergana Valley, located in the Syr Darya basin, is one of the most densely populated (14 million people, or 636 people per km^2) regions in Central Asia (Fig. 1). The Valley is shared between three countries, Uzbekistan, Kyrgyzstan, and Tajikistan, competing for its water resources, used for irrigated agriculture and hydropower. The ensuring risk of conflicts over water between upstream and downstream countries is high: "nowhere in the world is the potential for conflict over the use of natural resources as strong as in Central Asia" (Smith 1995, p. 351). Several small-scale water conflicts over the past fifteen years include ethnic strife in Osh, Kyrgyzstan between the Kyrgyz and the Uzbeks, in the Uzbekistan part of the Fergana Valley between Uzbeks and Meskhetian Turks, and in the transborder region of Isfara, Tajikistan, and Batken, Kyrgyzstan. In all these instances, the social unrest was due to the shortages of land and water resources (Weinthal 2002). Even though some experts believe that water interdependence in the Aral Sea basin countries is too high to allow a war, likely local conflicts over water, especially in multiethnic districts, may grow into full-scale military conflicts (Ohlsson 1999).

Study Area

The Fergana Valley is an important socio-economic region of Central Asia with highly fertile soils owing to the rivers of Naryn and Kara Darya, which confluence in the Valley to form Syr Darya. Irrigated agriculture has always been one of the major types of economic activity in the Valley, providing income and employment for its population. With large-scale development of irrigated agriculture in the second half of the twentieth century, numerous canals and reservoirs were built in the Valley, providing infrastructure for production of cotton and other water intensive crops.

With the 1991 dissolution of the Soviet Union, centralized water management system became a source of conflicts between the newly independent post-Soviet countries sharing the Valley. Besides the inherent conflict over the timing and amount of irrigation water

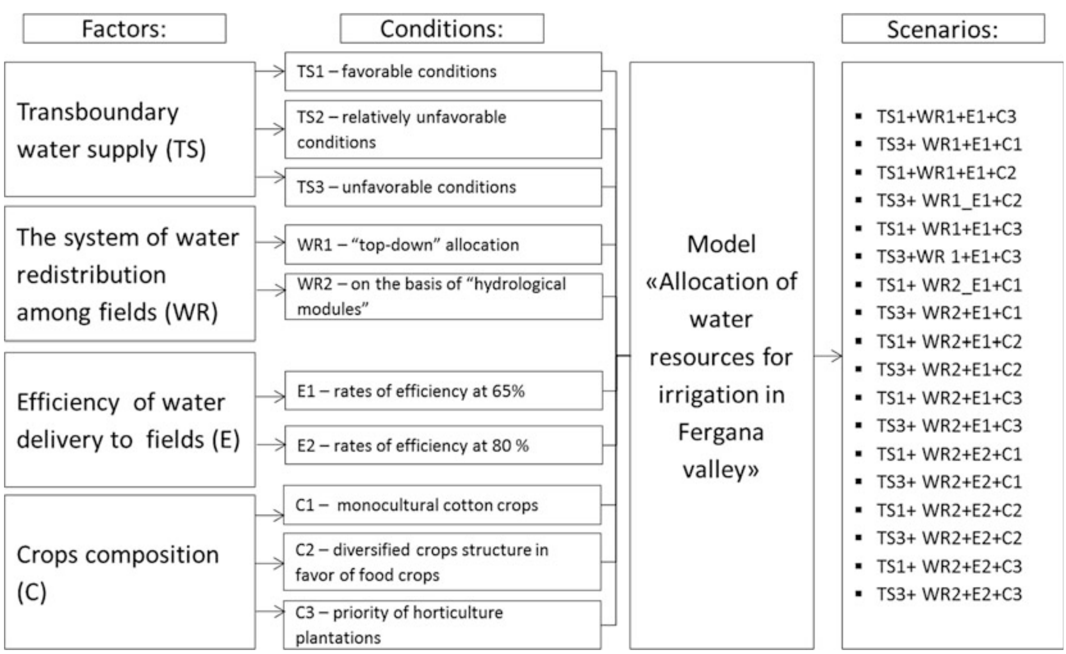

Fig. 2 Scenarios scheme of water use in irrigation of the Fergana Valley

withdrawal, shortages in energy resources in the upstream country of Kyrgyzstan forced a shift in the management of Kyrgyzstan controlled Toktogul water reservoir from prioritizing irrigation demands to maximize energy production. The major contradiction owes to Kyrgyzstan's inability to cover its electricity demand during winter seasons. When Toktogul water reservoir is managed for the needs of downstream irrigation, 75% of its annual water release should be made during the summer months («irrigation mode»), leaving little for energy production during the peak demand in winter months. Maximization of energy production reduces summer water release to only 45% of the total annual volume («energy generation mode») (Moller 2005), falling short of the downstream demand. These factors make modernization of the irrigation systems a priority for sustainable development in the Fergana Valley.

Data and Methodology

Climate Scenarios

The scenarios of future climate (2020s, 2050s, and 2080s) for three countries sharing the area adjacent to the Fergana Valley were developed from multiple general circulation models (GCMs) runs. To account for model-related data uncertainty, we used simulation results of five different GCMs: CGCM2, CSIROmk2, ECHam4, DOE PCM, and HadCM3. To account for the different paths of socio-economic development, for each of the GCMs we employed four IPCC scenarios: A1, A2, B1, and B2 (Nakićenović et al. 2000). A superposition of different GCM simulations and SRES scenarios (Mitchell et al. 2004) gave us arrange of future weather patterns for the countries of interest.

The 1961–1990 monthly temperature, precipitation, and water vapor pressure at the surface level, gridded at the 0.5° × 0.5° geographical latitude and longitude scale (Mitchell et al. 2004) was used for the base climate. The current and future climate data were temporarily downscaled with Andrew Friend's (1998) stochastic weather generator. Finally, the daily data were aggregated into the following five indices: mean annual temperature and precipitation, mean temperature and precipitation for the growing season—April through September, as well as potential evapotranspiration for the growing season.

Modeling Irrigation Water Deficit in the Fergana Valley

We developed a GIS-based model of the Fergana Valley water allocation for irrigation and used it to identify irrigated lands with potential water shortage. The following layers were included into the GIS:

- Land use: Irrigated lands under cotton, cereals, forage and horticulture, settlements, and bared lands (bogs, degraded areas, salt marshes). The layers were created from the Landsat7 imagery and SRTM90 digital terrain model at 1:400000 scale;
- Irrigation infrastructure: Water reservoirs, primary and secondary canals, streams and rivers, drainage network, water diversion units;
- Soils type, texture, and average groundwater level.

The intersection of the land use cover and irrigation layers resulted in 560 polygons representing complexes of agricultural fields irrigated with different canals.

We simulated a flow of irrigation water through the canals to identify those polygons facing water shortage in different climate conditions, accounting for the following factors:

- Transboundary water supply (TS)—amount of water entering the Fergana Valley from Kyrgyzstan's Toktogul and Uzbekistan's Andijan reservoirs;
- The policy of water redistribution (WR) among the fields;

- Efficiency of water delivery to the fields (E); and
- Crop composition (C).

For each of these four factors controlling water allocation between the fields, we differentiated several conditions of their manifestation.

For the first factor (TS), the following three conditions of transboundary water supply were used:

- TS1—optimal irrigational water availability based on the operation of the both Toktogul and Andijan water reservoirs in the irrigation mode (as it was before 1993);
- TS2—relatively unfavorable condition of water supply when Toktogul reservoir operates in the energy production mode while Andijan reservoir discharges maximal possible water to compensate the reduced water flow to the Fergana valley(as it was in 1998);
- TS3—energy production water management with minimal water flow from the both reservoirs that could happen in very dry year (for example, in 1987).

The second water redistribution factor (WR) is presented by two conditions of its manifestation. The current "top–down" approach for water redistribution between the fields WR1 gives priority to the fields located in the head of the canals while the fields located at the tail of the canals are withdrawing whatever water is left. An alternative so-called "hydrological module" approach WR2, applied in the Soviet times with taking into account the soil texture and groundwater level, is currently used in a few areas. The priority is given to the fields with light (sandy) soils and groundwater level below 5 m. This approach reduces waterlogging and secondary soil salinization while optimizing water use. Therefore, we considered such two water distribution conditions:

- WR1 "top–down" and
- WR2 "hydrological module" approach for water use optimization.

The next factor, water delivery to the field efficiency (E) depends on the local watering system infrastructure. The most common mode of watering the fields in the Fergana Valley is by furrows. The individual farmers often construct furrows with little attention given to terrain peculiarities of their plots. Furrows (digged directly in the ground without keeping in mind the relief features) lead to excessive water infiltration, contributing to waterlogging and salinization of soils. According to some estimates, furrows watering efficiency is not more than 65% at best, with 35% of water lost to infiltration (Mukhamedzhanov and Nerozin 2008). Meanwhile, the advanced technology of furrows' construction and water delivery lead to water efficiency of up to 80% (Laktaev 1978). Following these estimates, we used two conditions for water efficiency:

- Business-as-usual E1 = 65% and Advanced E2 = 80%.

Finally, the fourth factor of irrigation water demand varies with crop types. On average, rice uses 12,000 m^3 of water per ha, cotton—4900 m^3/ha, horticulture—3722 m^3/ha, and wheat—3144 m^3/ha. Based on this data, we used the following cropping structures' conditions:

- C1—a monoculture of cotton resembling the soviet time, with maximum water demand;
- C2—diversified crops' structure with priority given to winter cereals and rather high share of cotton, with a 1/3 reduction in water demand per ha;
- C3—prioritization of horticulture plantations combined with winter cereals, partially shifting irrigation demand to winter season, resembling the obligatory cropping system currently introduced in Tashkent region.

A combination of these options for water allocation, distribution, efficiency of delivery, and demand gave eighteen scenarios of irrigation water supply and demand (Fig. 2, note that not all of the 36 possible combinations were used,

Table 1 Current values and projected change in the difference between potential evapotranspiration and precipitation PET-P (mm) in the irrigated areas of Uzbekistan (Kirilenko et al. 2009)

	PET-P (mm)			
Period	A1	A2	B1	B2
Current	1041			
2020s	1185	1169	1187	1186
2050s	1391	1308	1286	1285
2080s	1645	1512	1367	1392

The mean of projections from five different GCMs

the ones with unlikely combinations eliminated). Further, the scenarios of future climate were taken into account through modification of the irrigation norms for different crops. The irrigation norms, established in the Soviet time, have been kept unchanged for a long period. Currently, the potential evapotranspiration in arid areas of Central Asia exceeds precipitation roughly by approx. 1500–2000 mm (Zonn 1986), which determines irrigation demand. In a warmer and dryer climate, this difference would increase, driving up crop irrigation norms.

The average flow of rivers and streams entering the Fergana Valley from surrounded mountains could be changed in new climate. The higher temperatures may affect melting of the glaciers in Pamir and Tyan-Shan, increasing water flow in Syr Darya and Amu Darya. The flow will, however, decrease after the glaciers exceed their replenishment capacity (Micklin 2007). In the Fergana Valley, however, even the initial water flow could decrease in mid-term spike may be unsubstantiated as the majority of its rivers are snow-fed (Chub 2007). Climate change is likely to reduce seasonal snow cover even in high mountains while projections of increase of precipitation remain uncertain. Taking into account the existing uncertainty, we assumed future water supply, and consequently, mean annual water discharge from the Toktogul reservoir to be in the range of current variability.

Results and Discussion

Climate Change Projections

Local meteorological data show a consistent warming trend in the Valley in 1970–2000 with no significant precipitation trend (Chub 2007). If continued into the future, the increase in annual temperature and small increase or decrease in precipitation in the entire region can make a negative impact on the agriculture in the region through increasing water demand for irrigational withdrawal. Micklin (2007), citing the earlier projections of the Main Administration for Hydrometeorology in Uzbekistan (Chub 2002), estimates the 2030s temperature growth of 0.5–3.5 °C in different parts of the Aral Sea basin countries with moderate up to 10% increase in precipitation. Similarly, Ososkova et al. (2000) projected a 3 °C temperature increase by the 2050s. Note that these estimates were considerably higher compared to the global temperature change projections, consistent with a generally accelerated temperature increase in the continental climate regions with cold winters.

Consistent with these earlier estimates, we found the 2020s temperature change in a 0.9–2.1 °C range compared to the 1961–1990 baseline period (Dronin and Kirilenko 2008). The change in annual precipitation was inconsistent,

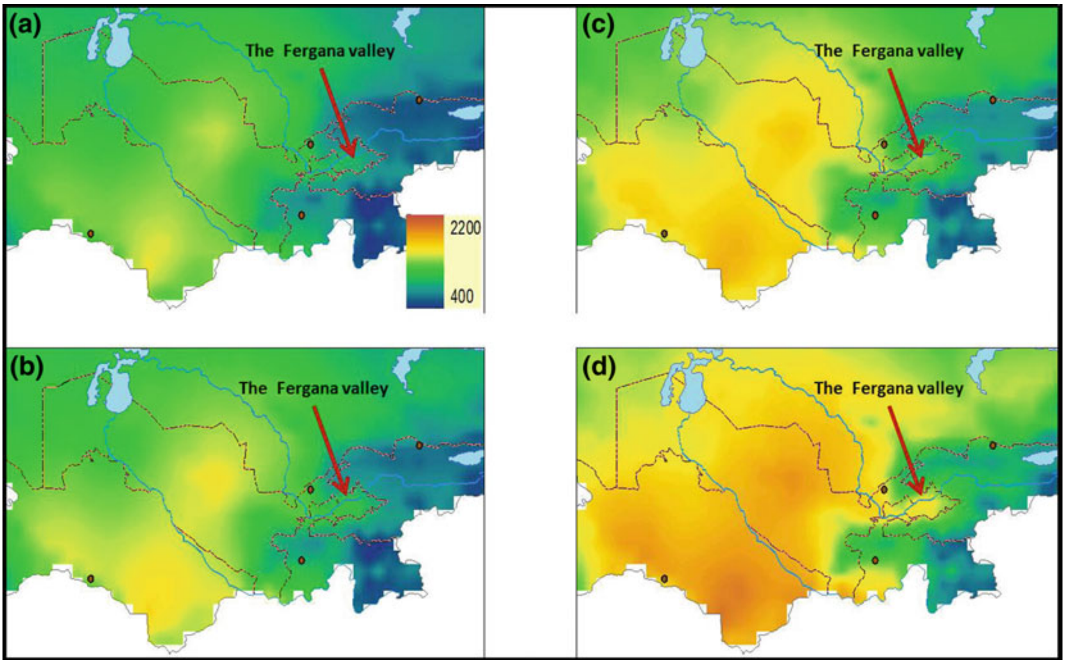

Fig. 3 Current (**a**) and future (**b** 2020s; **c** 2050s; **d** 2080s) difference between potential evapotranspiration and precipitation PET-P (mm). HadCM3 SRES A1FI scenario is shown. By *arrow*, we show location of the Fergana Valley (Kirilenko et al. 2009)

ranging between a small increase and small decrease. The projections for 2050s demonstrate much higher temperature increase between 1.7 and 4.7 °C. Finally, for the 2080s all GCMs simulated air temperature ranging from 3.9 to 7.8 °C. The precipitation change varied from −28 mm to +128 mm (in the mountains). Higher summer temperatures would increase the difference between potential evapotranspiration and precipitation (PET-P) by 13% in 2020s, requiring an additional 8% surge in water withdrawal for irrigation. By 2050s, PET-P increases by 26%, requiring a 16% increase in irrigation water withdrawal. Finally, a sharp increase of air temperature in 2080s elevates PET-P by 42%, leading to a 25% increase in demand for water withdrawal assuming under business-as-usual scenario (Table 1).

The geographical pattern of the impact of climate change on water withdrawal demand demonstrates considerable spatial heterogeneity would be different in different countries of the Central Asia (Fig. 3). Due to a larger increase in precipitation and fewer irrigated fields, the upstream countries (Kyrgyzstan and Tajikistan) and Kazakhstan show no or a very moderate increase in their irrigation water requirements, even though the relative climate change may become significant by 2080s. Turkmenistan and Uzbekistan, heavily relying on irrigated agriculture and experiencing the smallest increase in precipitation, would suffer the most, as their water irrigation requirements double by the 2080s.

Uzbekistan, which heavily relies on rice and cotton assist major food and cash crops, would be impacted by a sharp 5.2 °C temperature increase by the end of the century (average between the GCMs), with a small precipitation increase. This combination of high temperature growth with a small increase in precipitation would raise evapotranspiration rate significantly (Table 2). Note that the most extreme GCM simulations demonstrate an even higher warming of—up to 8.3 °C.

Following the regional pattern, in the Fergana Valley, a combination of high temperature

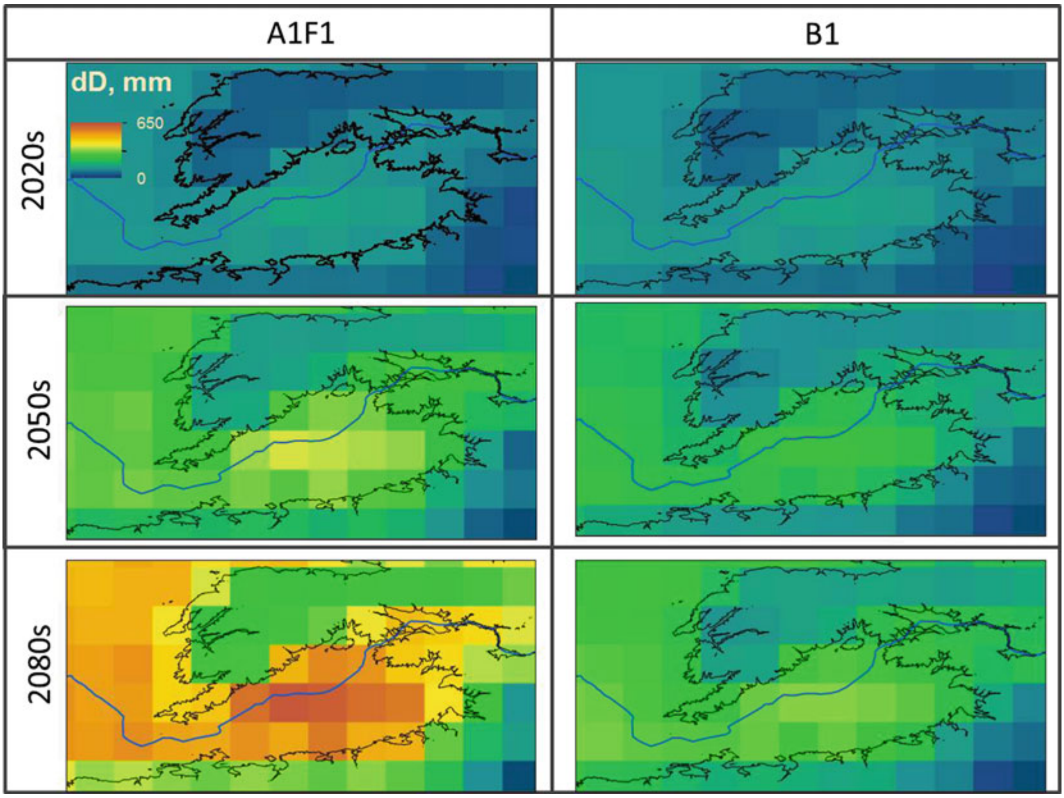

Fig. 4 Change of mean annual water deficit dD (the difference of potential evapotranspiration and precipitation) from the 1961 to 1990 average, mm. Future precipitation and potential evapotranspiration are computed as a mean value from the temperature and precipitation output of five GCMs (CGCM2, CSIRO2, ECHAM4, HadCM3, and PCM) for three decades surrounding the 2020s, 2050s, and 2080s. Two contrasting CMIP3 scenarios, A1FI and B1 are shown

growth with a small change in precipitation would increase mean annual water deficit (Fig. 4), and consequently, irrigation water demand: by 14% in 2020s, 23–33% in 2050s and 30–56% in 2080s, with the range determined by GCMs and SRES scenarios (Fig. 4).

Water Deficit in the Fergana Valley Under Climate Change

Three scenarios of water deficit under climate change and water management systems are shown in Table 2 and Fig. 5a, b, c.

The "business-as-usual" scenario (Fig. 5a) of allocating water resources for irrigation in the Fergana Valley (see Section "Modeling Irrigation Water Deficit in the Fergana Valley") assumes: (1) relatively unfavorable water supply during warm periods due to maximization of energy production at Toktogul reservoir in colder season with partially compensated water discharge in the warm season through Andizhan reservoir (TS-2); (2) "top–down" water allocation among the fields (WR-1); (3) diversified crop structure in favor of winter cereals with considerable area under cotton (C-2); and (4) a 35% loss of irrigation water to infiltration (E1). Under climate change, the "business-as-usual" scenario of water management leads to increasing area of agricultural lands under persistent water deficit from current 12% to 18.7% in 2020s, 27% in 2050s, and 38.2% in 2080s. The irrigation areas with water scarcity spread over are situated in the central part of Valley.

The intermediate scenario (Fig. 5b) with optimization of irrigation management (including crop structure, but keeping current mode of

Table 2 Share of agricultural lands under water stress (%) under three contrasting scenarios of irrigation water management in the Fergana Valley

Period	Relatively unfavorable water supply (TS2)		Favorable water supply (TS1) and optimized water management (optimal scenario)
	Current water management ("business-as-usual")	Optimized water management (intermediate scenario)	
2020s	18.7	8.3	5.2
2050s	27.0	16.0	13.9
2080s	38.2	20.2	23.2

The mean of projections from five different GCMs.

reservoirs' operation: TS-2, WR-2, E-2, C- 3, see Section "Modeling Irrigation Water Deficit in the Fergana Valley"), leads to a noticeable reduction in area under water deficit: to 8.3% in 2020s, 16% in 2050s, and 20.2% in 2080 (Table 2). Irrigation areas with water shortage are located in the central part and foothills areas.

The optimal scenario (Fig. 5c) of managing irrigated agriculture with Toktogul reservoir operation optimized for irrigation, reduced to 20% loss of irrigation water, and switching to horticulture and winter cereals(TS-1, WR-2, E-2, C-3, see Section "Modeling Irrigation Water Deficit in the Fergana Valley") leads to an even greater reduction in area under water stress from the current 12% to 5% in 2020s and 14% in 2050s. Still, the area under stress is high as 23% by 2080s (Table 2). Radical modernization of the irrigation system is needed to cope with water deficit in the Fergana Valley.

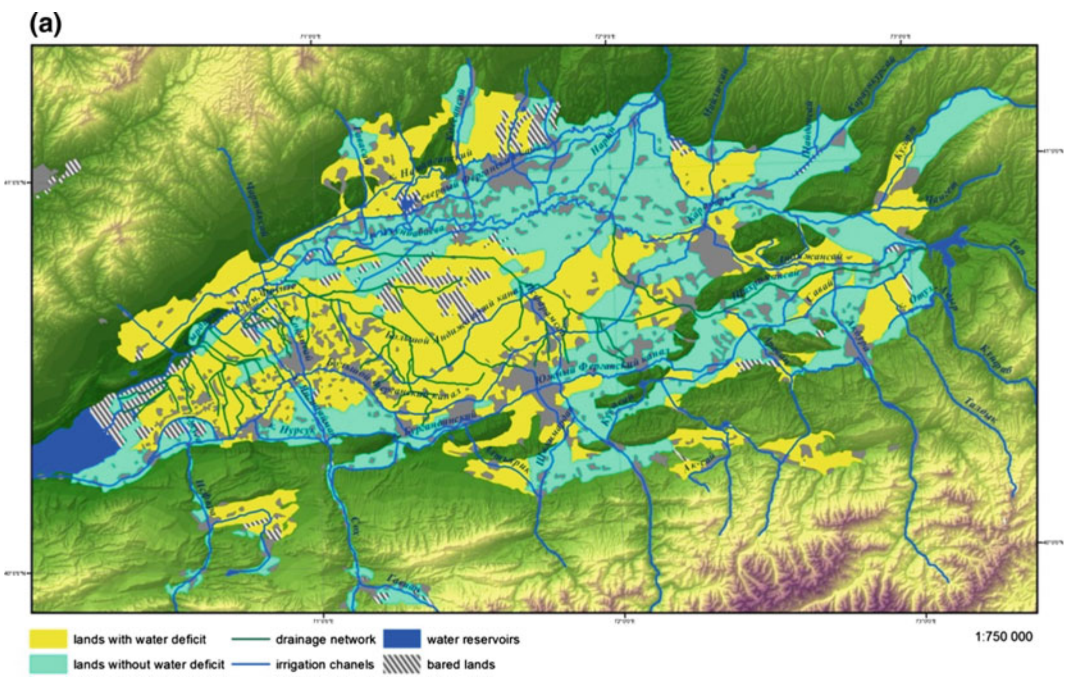

Fig. 5 **a** Projection of water deficit in the Fergana Valley under the 2080s climate and under the «business-as-usual» scenario of water management. **b** Projection of water deficit in the Fergana Valley under the 2080s climate and under «intermediate» scenario of water management. **c** Projection of water deficit in the Fergana Valley under the 2080s climate and under «optimal» scenario of water management

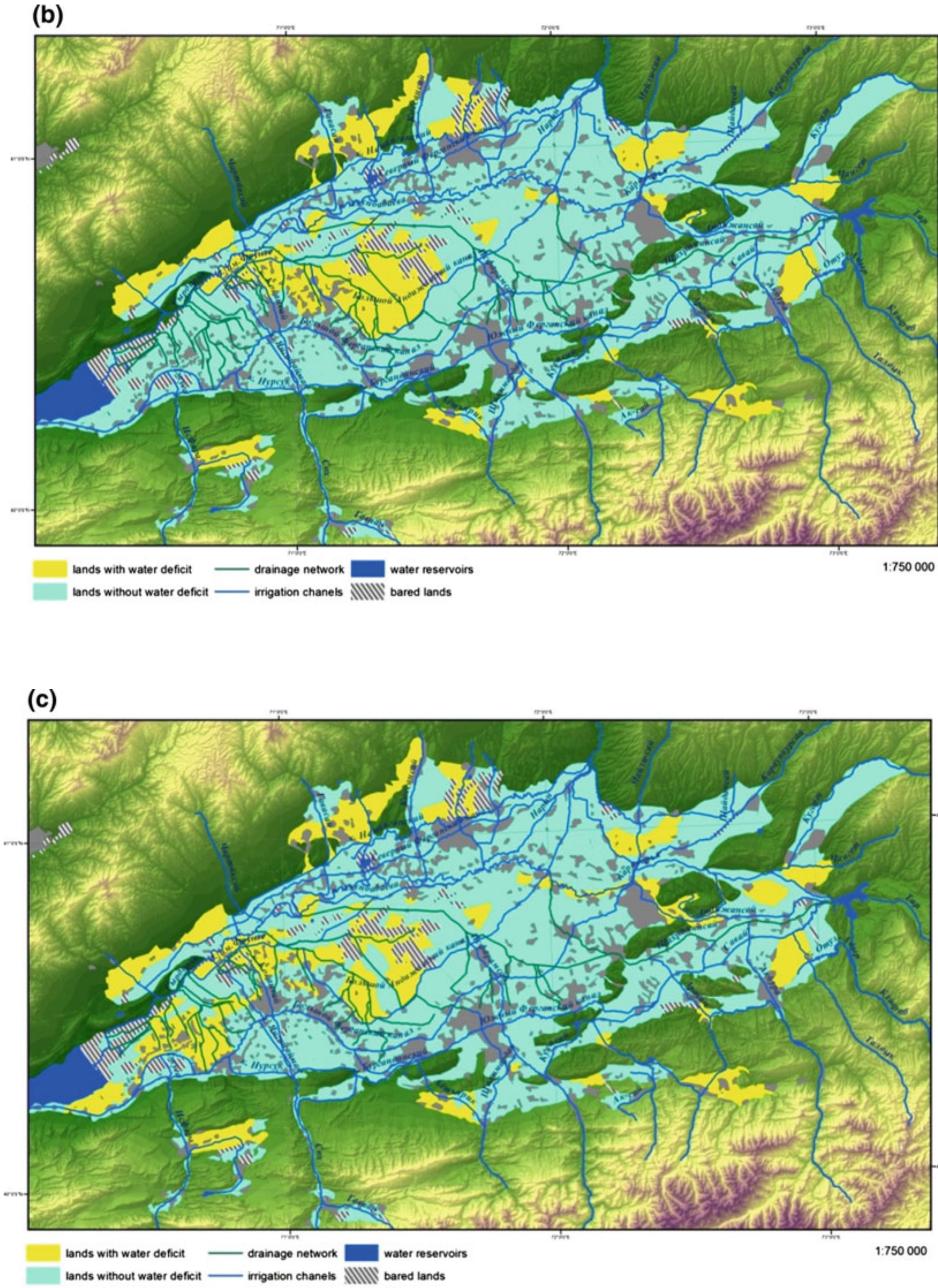

Fig. 5 (continued)

Notice a larger area under stress for 2080s compared to the intermediate scenario due to a larger area under water deficit controlled by Andizhan reservoir, which is managed in the business-as-usual regime as opposed to maximization of irrigation water flow in the intermediate scenario.

In addition to considerable water saving in short and mid-terms, the optimal scenario brings environmental benefits. Currently, the "business-as-usual" water management is responsible for widespread oil salinization, which in turn requires even more water to mitigate. Around 19% of agricultural lands are saline in the Fergana Valley. Productivity of cotton crop decreases by 10–20% on slightly saline soils, 30–40% on medium saline soils, and 60–70% on highly saline soils (Nerozin 1980). Between 1990 and 2005, agricultural water productivity (on cotton plantations) in the Fergana Valley dropped two to three times (Stulina 2010) and—to 0.24 kg/m^3 of water (Nerozin 2008), compared 0.46–0.8 kg/m^3 on the best lands (Mukhamedzhanov 2007). Murray-Rust et al. (2003) estimated that 3000–3500 m^3/ha of water are spent on each flushing of saline soils with two to four flashings normally required after the end of harvest in November–December after harvesting season, when level of groundwater is the lowest. This results in excessive consumption of water in irrigation: using 11,000 and 14,000 m^3/ha of water for irrigation (World Bank 2003) versus 7700 m^3/ha global average (FAO AQUASTAT).

The excess water is discharged through drainage into two major rivers of the region, gradually reducing downstream water quality. The majority of drainage systems in the region are in disrepair, with outdated water storage and distribution infrastructure. At the end of the 1960s, water salinity did not exceed 1 g/l even in the lower reaches of Amy Darya and Syr Darya (Sokolov 2009). Currently, water mineralization in Syr Darya is changing from 0.45 to 0.6 g/l in the upper flow to 1.1–1.4 g/l leaving the Fergana Valley (Valentini 2004), and to 9–10 g/l in the low flow (EC 1995).

The outdate drainage system, which is even harder to restore and maintain than the irrigation canals, leads to waterlogging (World Bank 2003). Water table rise is widely observed (Mukhamedzhanov 2007), and currently, the groundwater table on 25–50% of irrigated lands in the Fergana Valley is shallower less than 2 m, contributing to high risk of waterlogging (Baknell 2003). In areas with high water table (below <2 m), increased mineralization of groundwater also leads to soil salinization. Higher groundwater salinity influence on concentration of the total dissolved salts in drinking water up to 3.5 g/l in some places, well above the 1 g/l safe level set by the Uzbek government (Small et al. 2001). Additionally, waterlogging leads to bacterial and chemical (e.g., pesticide) pollution of drinking water (Baknell 2003).

Conclusion

Unsustainable practices of agricultural development in the Aral Sea basin countries led to numerous problems related to mismanagement of natural resources. Among problems, water scarcity has the highest potential of generating transboundary conflicts (Smith 1995). While the Aral Sea countries have been independent for twenty-five years, they still lack the appropriate institutions to resolve the issues of cooperative water management. In the absence of political compromise between the stakeholders at the regional and national levels, there are few indications of improving water regulation for mutual benefit. At subnational level, rural poverty is responsible for poor water management resulted in widespread waterlogging, erosion, and salinization. Meanwhile, the entire situation can be strongly deteriorated in the region because of climate change.

The Fergana Valley is the key region to explore above-mentioned problems and find ways for their solution. Prior to 1993, annual barter agreements between upstream Kyrgyzstan and downstream Uzbekistan and Kazakhstan regulated exchanges of upstream water resources for end-user energy. This system collapsed possibly due to concerns over reliability of its implementation. The agreements were usually signed late spring, at the peak of irrigation water concerns in the downstream countries and lower concerns over energy in Kyrgyzstan, which has the highest energy demand in winter. Because of Kyrgyzstan's anxiety whether enough fossil fuels would be provided under the barter agreement, it saves the water to produce hydroelectricity (IGC 2002). Meanwhile, Kyrgyzstan's hydropower resources are still insufficient to cover energy demand during the winter season, which creates an opportunity for a "win–win" solution if trust and transparency come back to the region.

One obstacle for better water management on a local level is rural poverty. Water user associations (WUAs) emerges with the goal to solve water management challenges after the collapse of the Soviet Union: (1) dissolution of large collective farms (i.e., kolkhozes) with emergence of thousands of water users utilizing an irrigation system designed for centralized management; (2) problems with reliable and timely water delivery; (3) willingness and ability, including a financial capacity, of local water administrations to do on-farm water management, including water delivery, allocation, drainage, operation, and maintenance of irrigation system (Anarbekov and Pinkhasov 2007).

Implementation of water pricing could create additional incentives for improved water management and technological advances in Central Asia (Dukhovny 2008). Current water prices are too low to compensate the operation and maintenance costs of water storage and distribution systems (Spoor and Krutov 2003; Wegerich 2001). The World Bank (2003) study modeled the effects of applying world market prices both on water and crops in irrigated agriculture of Uzbekistan and Tajikistan. Even under the most pessimistic assumptions, with cotton and wheat prices at the currently low level, the study found that only 12% of irrigated land in Uzbekistan became unprofitable, while under a very modest 10% price increase, only 1–2% of the arable lands became unprofitable.

Transition to new crop composition in the Fergana Valley is another important measure to reduce the lands under water deficit. To sustain both the agricultural production and environment in the Aral Sea basin, the International Food Policy Research Institute (IFPRI) recommends growing cotton on not more than 40% of the irrigated land, while increasing the area under wheat and maize area up to 32% (Cai et al. 2006). The projected cereal production in the region for 2020s is an increase by 31% (from 10.69 to 14.06 million tons), leading to the area under cereals growing by 0.25% annually—compare with 0.03% for the rest of the former Soviet Union (Babu and Tashmatov 2000). Transition to horticulture production is another attractive market option for the Uzbekistan. Since 2004, the country's export volumes (Yuldashbaev 2014) of fruits and vegetables increased seven times while export value—more than 25 times (up to $1.5 billion in 2013).

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Long-Term Trend of Vegetation in Bundelkhand Region (India): An Assessment Through SPOT-VGT NDVI Datasets

Arnab Kundu, D.M. Denis, N.R. Patel and Dipanwita Dutta

Abstract

Vegetation cover is an important natural resource of the terrestrial ecosystem, and it has significant role in preserving the ecological balance in an area. Analyzing the dynamic pattern of vegetation cover and its trend can be a key to explain any unusual condition of the environment. Bundelkhand, located at the central part of India, has experienced recurrent drought events in last decade, and considering the devastating effects of drought in that region, the present study aims to explore the long-term trend of vegetation using geo-spatial technology. The remote sensing-based SPOT-VGT NDVI data were used to identify the changes in vegetation with time. The normalized difference vegetation index (NDVI) has proven to be a very powerful indicator of global vegetation productivity. In this study, we used linear regression model for evaluating the long-term trend of vegetation considering NDVI as dependable and time as independent variable. Our results showed that there is a varying pattern of vegetation trend and its response to rainfall.

Keywords

NDVI · Vegetation dynamics · Linear regression · Trend analysis

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Introduction

Vegetation is being considered as a significant element of the ecosystem and also a most vital component of biosphere (Billings 1952). It plays an important role in the interaction among atmosphere, living organisms, and soils on several spatial and temporal scales. The dynamics of vegetation, productivity and its inter-annual changes play a key role to recognize the strong relationship between rainfall and the growth of vegetation from a regional to global scale (Hilker et al. 2014; Hawinkel et al. 2015). For identifying and monitoring the long-term changes in vegetated areas, optical remote sensing has been popularly used since the early 1980s. The relationship between rainfall and vegetation response has been observed very robust way by various satellites in different spatial and temporal resolutions (Wang et al. 2003; Mendez-Barroso et al. 2009; Dutta et al. 2013; Kundu et al. 2015a).

Among various remote sensing-based vegetation indicators, normalized difference vegetation index (NDVI) has proved to be very useful for the successful assessment and delineation of landscape and their behaviors in many regions of the globe (Nemani and Running 1989; Stoms and Hargrove 2000; Mazvimavi 2003; Wang et al. 2004; Maselli et al. 2006; Donohue et al. 2009; Kundu and Dutta 2011; Dutta et al. 2013; Sahoo et al. 2015; Kundu et al. 2016). NDVI has been broadly used to point out vegetation dynamics for different regions (Tucker et al. 1986; Myneni et al. 1997; Nemani et al. 2003; Donohue et al. 2009, 2013; Piao et al. 2011; Kundu and Dutta 2011; Dutta et al. 2013, 2015; Kundu et al. 2014; Sahoo et al. 2015; Kundu et al. 2017). Interrelationship among NDVI, rainfall, and temperature has been used in several studies to assess the effects of climate change on vegetation and its transformation for a longtime period. The growth of vegetation is influenced by rainfall; it is entirely dependent on the quantity, timing, and frequency of rainfall, especially in arid and semiarid regions (Fravolini et al. 2005; Liu et al. 2012; Gamon et al. 2013; Dutta et al. 2015; Kundu et al. 2015a, b; Fan et al. 2016; Kundu et al. 2017). Martiny et al. (2006) analyzed the relationship between mean seasonal variations of rainfall and NDVI at a regional scale in semiarid regions of Africa. Prasad et al. (2007) examined the relationship between NDVI and climatic parameters to determine which climatic variable (temperature or precipitation) best explains variation in NDVI. In addition, they also assessed how quickly and over what time periods does NDVI respond to different precipitation events over an area.

Analyzing the vegetation dynamics and pattern of NDVI trend is crucial over Bundelkhand region considering the vulnerability associated with productivity of this fragile ecosystem. This area has experienced frequent drought in last decades, and severity of those recurrent drought events proved failure of all mitigational efforts. Till now, the time trend of vegetation has not been deeply investigated over this region. So, identifying the greening or degreening trend can play an effective role in analyzing the root cause behind such recurrent drought events. In this context, the present study aims to assess the temporal trend of vegetation and its spatial variation over the Bundelkhand region.

Study Area

The Bundelkhand region is located in the middle part of India, geographically between 23°20′N and 26°20′N latitude and 78°20′E and 81°40′E longitude. This area is bounded by Indo-Gangetic plain in the north, and the undulating Vindhyan mountain range in northwest to south direction. There are total thirteen districts within this region, i.e., Jhansi, Jalaun, Lalitpur, Hamirpur, Mahoba, Banda, and Chitrakoot of Uttar Pradesh and Datia, Tikamgarh, Chattarpur, Damoh, Sagar, and Panna of Madhya Pradesh state (Fig. 1).

Materials and Methods

Datasets

NDVI Data

Normalized difference vegetation index (NDVI), the most commonly used spectral vegetation

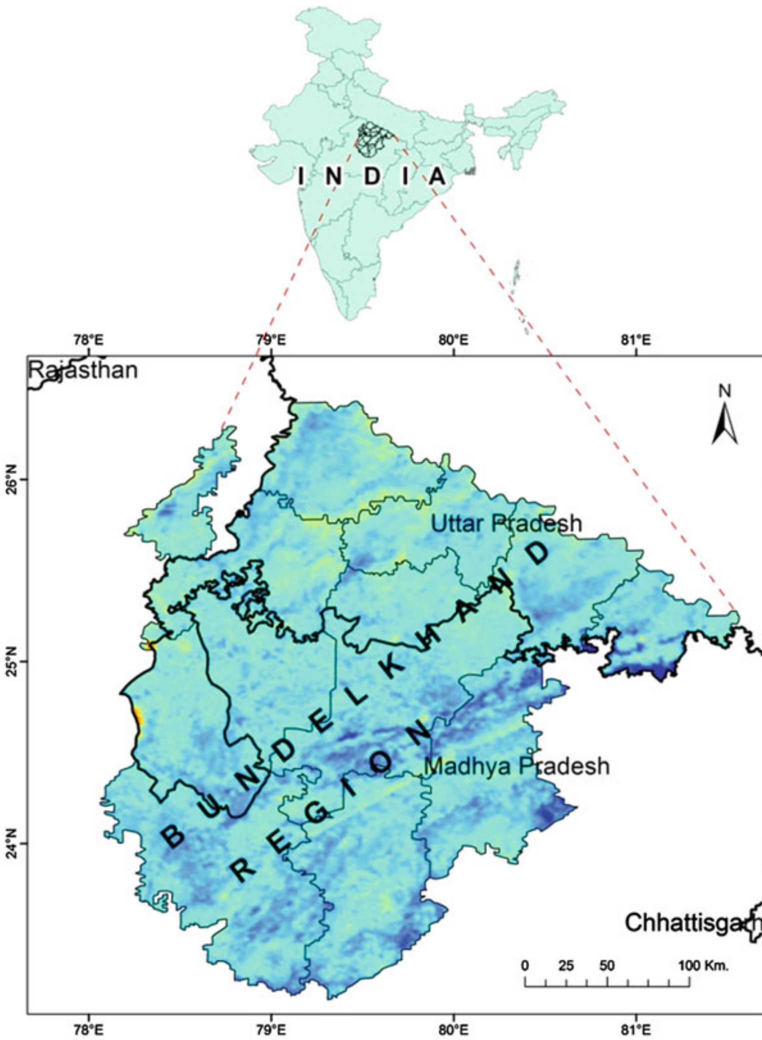

Fig. 1 Location map of study area

index, was first used by Rouse et al. (1973). It is an efficient index for monitoring green biomass, estimating leaf area index and crop yield (Jensen 1996; Thenkabail et al. 2004). This index is written by following formula (Eq. 1):

$$\mathrm{NDVI} = (\mathrm{NIR} - R)/(\mathrm{NIR} + R) \qquad (1)$$

It ranges from −1 to +1; negative NDVI values indicate open water bodies, and positive values show the areas covered by green vegetation. Multi-temporal NDVI dataset was derived from the Système Probatoire d'Observation de la Terre (SPOT) VEGETATION (VGT) sensor 4–5 from 1998 to 2013 with a spatial resolution of 1 km. The data were downloaded from the VGT data archive (http://free.vgt.vito.be). The Vlaamse Instellingvoor Technologisch Onderzoek (VITO) routinely operates atmospheric and angular corrections of reflectance data from SPOT-4/VGT-I and SPOT-5/VGTII. Atmospheric noises related to water vapor, ozone, and aerosols inherent in the raw data are corrected using a simplified method for atmospheric corrections (SMAC) (Rahman and Dedieu 1994). In addition, each 10-day composite dataset was corrected using the maximum value composite (MVC) algorithm to minimize further non-vegetation effects (Holben 1986; Maisongrande et al. 2004).

Rainfall Data

The Tropical Rainfall Measuring Mission (TRMM) is a joint mission between the National Aeronautics and Space Administration (NASA) and the Japan Aerospace Exploration Agency (JAXA). It was launched in 1997 and ended collecting data on April 15, 2015. TRMM observes the rainfall rates over tropical and subtropical regions of the world. The estimates are provided in 0.25° X 0.25° gridded datasets globally. The long-term monthly product of TRMM for the period 1998–2013 was used for the present study.

Methodology

The corrected decadal NDVI products of each month (1st, 11th, and 21st) were combined to estimate the monthly maximum NDVI (*MNDVI*). It was performed by following the maximum value composite (MVC) technique proposed by Holben (1986).

Maximum NDVI

$$\text{MNDVI} = \max\left(\text{NDVI}_1,\ \text{NDVI}_2,\ \text{NDVI}_3\right) \tag{2}$$

where MNDVI = monthly maximum NDVI

NDVI_1, NDVI_2, NDVI_3 = maximum NDVI In the first, second, and third 10-day composites of every month generated by MVC method. It has been considered as more suitable for estimating the integrated monthly NDVI as the chances of errors related to cloud contamination, and broad solar zenith angles are being largely reduced (Stow et al. 2007; Zhang et al. 2012).

In order to estimate the temporal trends of annual mean NDVI at pixel level, a simple linear regression model was applied considering time as the independent variable (x) and NDVI as the dependent variable (y). Several studies established that linear regression model can successfully distinguish long-term trend of vegetation characteristic as well as its interrelationship with climatic aspects (Zhang et al. 2012; Eckert et al. 2015).

Slope of regression equation (b) = $\text{NDVI} = (\text{NIR} - R)/(\text{NIR} + R)$ (3)

The resultant output of temporal trend analysis consists of the correlation coefficients (r) and regression slope (b), which are being considered as the strength and magnitude of the calculated trend (Fensholt and Proud 2012).

Results and Discussions

Mean Annual NDVI

The 10-day composite SPOT-VGT NDVI images were converted into monthly datasets by using maximum value composite algorithm (MVC). These monthly NDVI images of every year were then used for estimating the mean annual NDVI value. It is worthy to mention that NDVI is a well-accepted method for estimating vegetation dynamics which reflects the status of vegetation through measuring the chlorophyll content. It has been considered as a reliable indicator for assessing vegetation cover of an area. In addition, it is useful for identifying the different land use and land cover since the range of NDVI varies with diverse components of the earth surface.

It can be observed from the composite images of June and December that there is an uneven pattern of NDVI in spatio-temporal scale (Figs. 2 and 3). Areas with high NDVI values were observed in the south, central, and partial part of eastern of the study area. The areas toward south, central, and east are having higher NDVI due to cultivation of kharif crops using monsoonal water. June is the initial month of kharif season, so vegetation dynamics of agricultural lands was not prominent in most of areas, especially where cultivation is dependent upon monsoonal rainfall. However, the areas under dense vegetation like Bundelkhand upland in the central and Sagar, Damoh (Vindhyanchal) plateaus in the south represent relatively high NDVI over the years (Fig. 2). The northern part of study area characterized by undulating plains comprising Jalaun, Hamirpur, Banda, Jhansi, and Chitrakoot districts

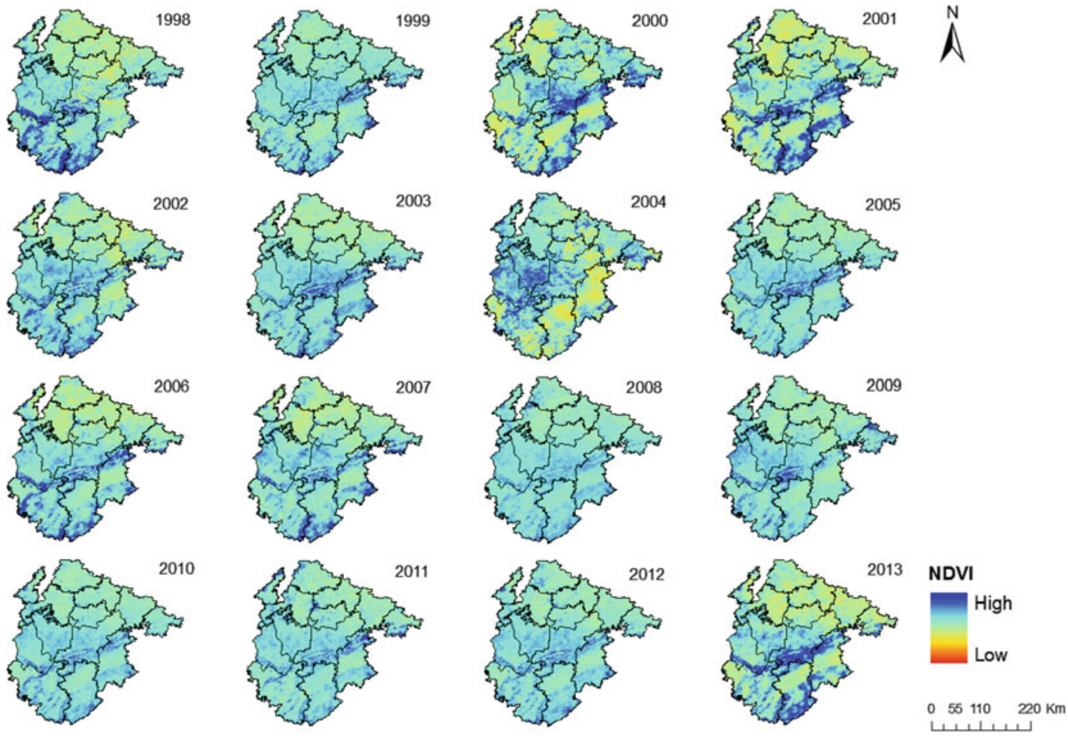

Fig. 2 Maximum value composite (MVC) NDVI of June (1998–2013)

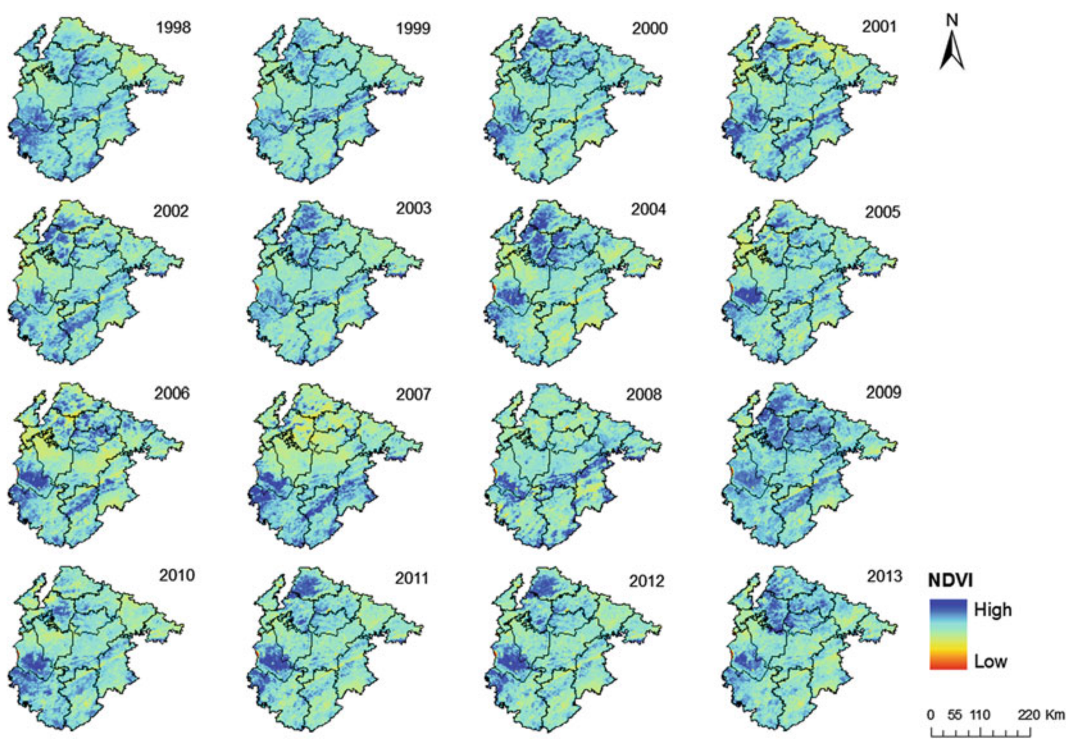

Fig. 3 Maximum value composite (MVC) NDVI of December (1998–2013)

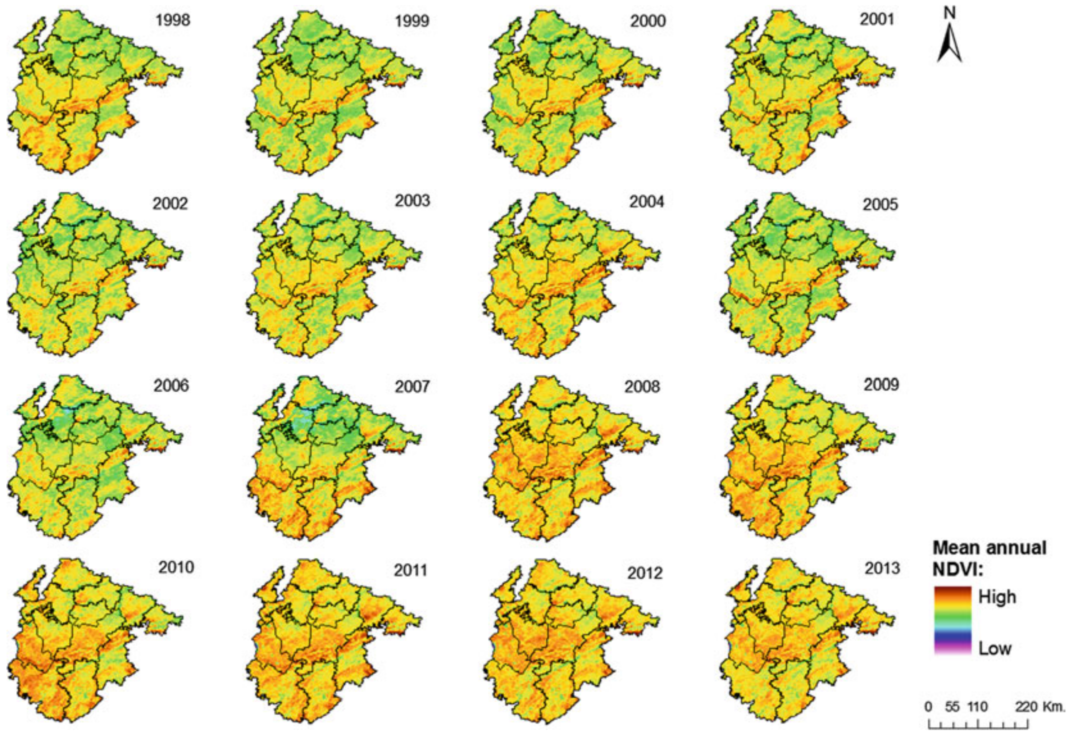

Fig. 4 Spatio-temporal pattern of mean annual NDVI in Bundelkhand (1998–2013)

showed relatively less vegetation in the majority of the years which could be explained by the seasonal fallow situation of its extensive agricultural lands.

It is evident in the northern and western parts of study area that NDVI value is higher during the month of December (Fig. 3). Generally, rabi crops are cultivated during that month which enhanced the overall vegetation growth of the area. It is notable that NDVI values were relatively less in central parts of study area specifically in the Tikamgarh, Chattarpur, and Mahoba districts (Fig. 3). The land use and land cover map of the study area reveals that these areas with relatively low NDVI consist plateau and hilly areas which were characterized by impermeable land with less vegetation. It is also noteworthy that NDVI of these areas were different in summer and winter months (Figs. 2 and 3). It can be explained by seasonal variation of phenology of vegetation during those seasons.

The mean annual NDVI image of each year estimated by averaging the MVC NDVI of different months has been used for estimation the time trend of NDVI at pixel level. This time trend analysis was carried out using the mean annual NDVI images of sixteen years (1998–2013). It can be observed that central and southern districts (Chattarpur and Sagar) of the study area consist of moderate-to-high NDVI values (Fig. 4). Rest of the districts of the study area shows moderate-to-low values of NDVI indicating sparse vegetation cover over there.

Temporal Trend of NDVI

In order to identify the temporal trend of NDVI, a simple but popular linear regression model has been applied considering time as independent variable (x) and average annual NDVI as dependent variable (y). This model is effective to monitor

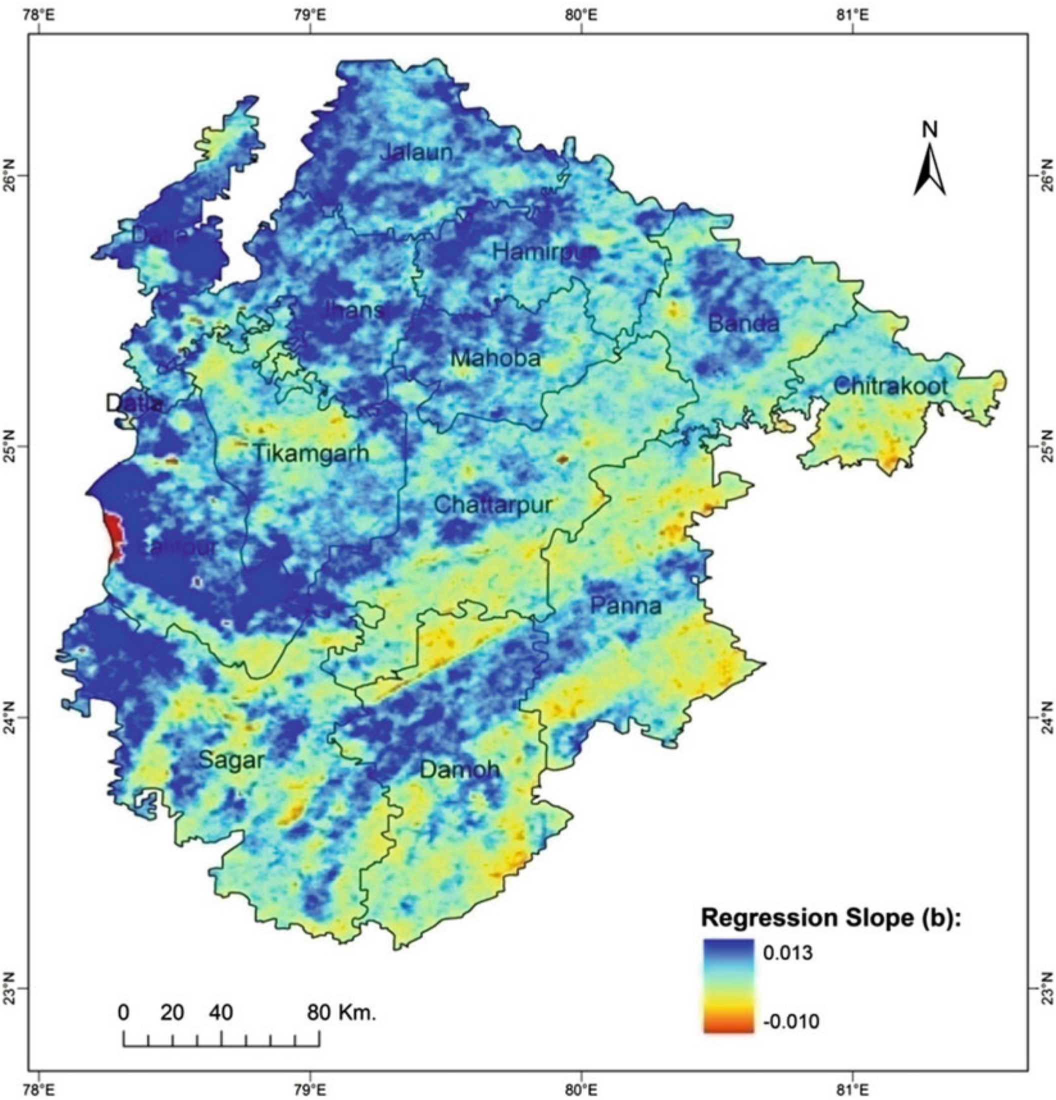

Fig. 5 Regression slope (*b*) of NDVI trend

the increasing or decreasing pattern of vegetation condition using long-term NDVI images. The regression slope (*b*) image of NDVI time trend model shows a significant pattern of NDVI in Bundelkhand region (Fig. 5). Areas with notable enhancement in vegetation cover can be observed (shown by deep blue) in parts of Lalitpur, Jhansi, Jalaun, Hamirpur, Mahoba districts and in small pockets of Banda, Panna, Damoh, Sagar, and Chattarpur districts (Fig. 5). On the contrary, the negative trend slope was observed in the small patch of Chitrakoot, Panna, Chattarpur, Damoh, and Sagar districts. The part of Chitrakoot, Panna, Chattarpur districts in the southern zone depicts significant degradation in vegetation trend. It is noteworthy that the spatial pattern of negative NDVI was in good agreement with the pattern of drought years of the Bundelkhand area. These areas have experienced recurrent drought due to high rate of surface runoff in spite of high rainfall.

The high rate of runoff and depletion of green vegetation has caused the negative trend in

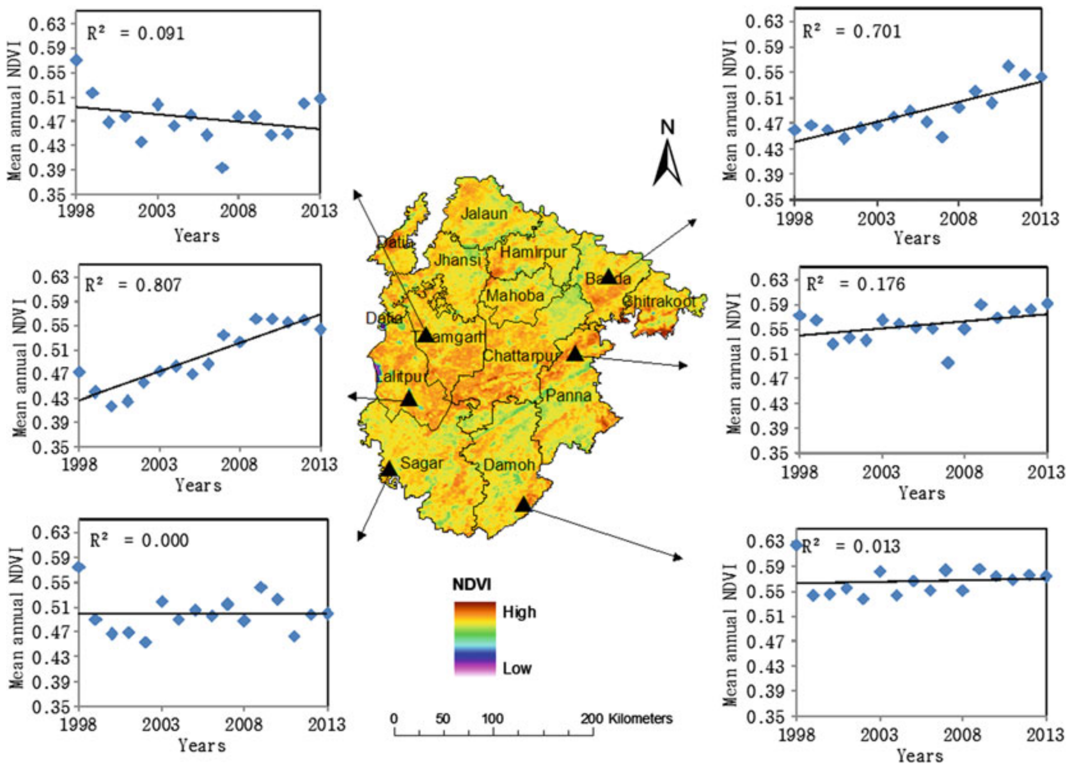

Fig. 6 Temporal trend of mean annual NDVI in various locations

NDVI values in those areas. However, the part of districts like Chitrakoot, Panna, Chattarpur, Damoh, and Tikamgarh showed a stable condition in NDVI pattern. However, most of the districts of Bundelkhand area experienced slow increasing trend of NDVI during the period. The maximum value of regression slope was observed in Datia district (0.006), followed by Hamirpur (0.005), Jalaun (0.005), Jhansi (0.005), Lalitpur (0.005), Mahoba (0.005). On the other hand, lowest regression slope was found in Chitrakoot district (0.002). In addition, six hot spots were identified for further study and they clearly depict the decreasing and increasing trend of NDVI over the time period (Fig. 6).

The northern part of the study area receives higher rainfall than southern part. Mainly, the southern area is characterized by hard rocks, undulating terrain with uneven slope, whereas the northern part consists of alluvial plains. The statistics depicted in detail about a range of NDVI–rainfall correlations over the study region (Table 1). The Bundelkhand region is primarily rain-fed and has < 25% of cropland with double cropping system that faced frequent drought hazard. The past reports reveal occurrences of seven droughts in last 16 years (Patel and Yadav 2015). The fluctuation of NDVI value is interrelated with the production of crops and natural vegetation growth. The pattern of vegetation growth and their responses to rainfall can be efficiently identified through the correlation between NDVI and rainfall. It can be observed that most of the districts are having moderate-to-strong positive correlation indicating the climatic influence on vegetation over there (Table 1). The areas with an increasing trend of NDVI and higher correlation indicate the growth of vegetation as a result of climatic effect in the Datia, Jalaun, Jhansi, Mahoba districts. Whereas, the districts like Sagar, Panna, Damoh reveal a different condition as vegetation cover of those

Table 1 Spatial statistics of correlation coefficient (NDVI–rainfall)

	Correlation coefficient: NDVI–rainfall				
Name	Min	Max	Range	Mean	Std
Banda	0.0886	0.7967	0.8853	0.3842	0.1525
Chattarpur	0.5426	0.7224	1.2650	0.3153	0.1446
Chitrakoot	0.4098	0.8277	1.2375	0.3662	0.1778
Damoh	0.4777	0.6712	1.1488	0.1325	0.1720
Datia	0.1928	0.8934	1.0862	0.4508	0.2419
Hamirpur	0.2062	0.7971	1.0033	0.4150	0.1484
Jalaun	0.1958	0.8491	1.0448	0.3829	0.2043
Jhansi	0.5417	0.8067	1.3484	0.3800	0.1976
Lalitpur	0.7100	0.6922	1.4022	0.2643	0.1905
Mahoba	0.6616	0.7326	1.3942	0.3956	0.1440
Panna	0.2936	0.6824	0.9759	0.2572	0.1463
Sagar	0.4738	0.6528	1.1266	0.0312	0.1556
Tikamgarh	0.5946	0.7985	1.3931	0.4488	0.1153

districts experiencing negative trend whereas, NDVI–rainfall correlation was found relatively weak. This certainly explains the presence of other factor controlling vegetation trend of the area. The negative trend of vegetation in those areas can be explained by high rate of runoff or anthropogenic activities like deforestation and conversion of vegetation cover.

Conclusions

The study analyzed sixteen-year composite (1998–2013) SPOT-VGT NDVI datasets to detect temporal trend of vegetation in Bundelkhand, an area affected by frequent droughts. In order to estimate the NDVI trend, linear regression model was used considering time as independent and NDVI as dependable variable. The regression slope of this model reveals a varying spatial pattern of vegetation trend in the area; the northern and northwestern parts are characterized by positive NDVI trend, whereas the southern and southeastern parts indicate negative or decreasing trend. The interrelationship between NDVI and rainfall reveals that rainfall plays a major role in such pattern of NDVI trend. Significant correlation coefficient between these variables confirms the climatic impact on increasing or decreasing trend of vegetation over there. The study also reveals the efficiency of SPOT-VGT time series datasets for identifying vegetation trend at regional level. However, for analyzing the underlying causes of recurrent drought events over the area, detailed historical datasets including livestock practices, soil and land management, topography, and hydrology are essentially required.

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Variability of Temperature and Rainfall in the Upper Beas Basin, Western Himalaya

Seema Rani and S. Sreekesh

Abstract

Temperature and rainfall affect both the spatial and temporal patterns of water availability, especially in the Himalayan environment. Hence, it is imperative to analyse the trends in temperature and rainfall. The present study aimed to quantify the inter-annual and intra-seasonal variability in these climate variables at Manali and Bhuntar of the upper Beas river basin. Daily temperature data, including minimum temperature (T_{min}), maximum temperature (T_{max}), mean temperature (T_{mean}), lowest minimum temperature (L_{min}), highest maximum temperature (H_{max}), amount of rainfall and number of rainy days of Manali and Bhuntar for the period 1980–2010, were obtained from the India Meteorological Department. The Mann–Kendall and Theil–Sen's slope nonparametric tests were used for the determination of trends and their magnitude. The findings indicate that the upper Beas basin experienced a warming trend at the rate of 0.031 °C/year during the period of analysis. Range of temperature showed a significant decline in the basin. Rainfall showed a significant decreasing trend at Manali. The number of rainy days also showed a reduction at Manali during the period of study. Significant variation has been observed in rainfall intensity in the region over the study period. It is not possible to rule out the link between the warming trend and increase in anthropogenic activities in lower part of basin.

Keywords

Temperature · Rainfall · Mann–Kendall test · Theil–Sen's slope estimator

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Introduction

One of the most important concerns confronting the Earth is undoubtedly the threat of climate change. Climate change or variability can be quantifiable through its key elements such as insulation, air temperature, precipitation, humidity, and wind. Evidences of variations in these key elements are reported around the world, though the degree of variations varies over time and space. Air temperature has been used widely for climate variability assessment around the globe (IPCC 1996, 2001; Tank et al. 2006; IPCC 2007, 2013) because it is expected that the changes in it will also influence the other climate variables such as precipitation, relative humidity, evaporation, and wind speed. It is an important input to climate models and climate change impact modelling at global and regional levels (Boyer et al. 2010; Luo et al. 2013; Bhatt et al. 2013). According to the Fifth Assessment Report of Intergovernmental Panel on Climate Change (IPCC 2013), the global combined land and ocean temperature data indicate an increase of about 0.89 °C during 1901–2012. Several studies in India have also used air temperature as a key indicator to understand the variability and change in climate (Arora et al. 2005; Gadgil and Dhorde 2005; Dash and Hunt 2007; Dash et al. 2007; Singh et al. 2008; Pal and Al-Tabbaa 2011; Jhajharia and Singh 2011; Singh et al. 2013; Dash et al. 2013; Duhan et al. 2013). Jain and Kumar (2012) reviewed the studies pertaining to trends in air temperature over India and found that the annual mean, maximum and minimum temperature shows significant warming trends of 0.51 °C/100 years, 0.72 °C/100 years and 0.27 °C/100 years, respectively, during 1901–2007.

Dash et al. (2007), Bhutiyani et al. (2007), and Dimri and Dash (2012) found the evidences of warming in the Western Indian Himalaya also. Dash et al. (2007) found that annual mean maximum temperature has increased by 0.9 °C in the Western Indian Himalaya during 1901–2003, and much of this observed trend is related to increases after 1972. This study also observed a sharp decrease in the annual mean minimum temperature by 1.9 °C in the region. Bhutiyani et al. (2007) estimated an annual warming rate of about 1.6 °C/100 years, with the annual mean minimum temperature rising at relatively lower pace than the annual mean maximum temperature during 1901–2002. According to this study, warming is particularly noteworthy in mean minimum (1.7 °C/100 years) and maximum temperature (1.7 °C/100 years) of the winter season. A warming trend over the Western Indian Himalaya was also observed by Dimri and Dash (2012) with the greatest increase in mean maximum temperature (1.1–2.5 °C) of winter (Dec–Feb) during 1975–2006.

Attempts have also been made around the world to evaluate the inter-annual and intra-seasonal variability in the rainfall (Diaz et al. 1989; IPCC 1996, 2001; Tank et al. 2006; IPCC 2007, 2013; Westra et al. 2013). The studies highlighted important changes in rainfall at the global scale, though changes vary from region to region. At the global scale, downward trends in precipitation have dominated in the tropics since the 1970s, while in South Asia, an increase in summer monsoon mean rainfall is predicted in the near future (IPCC 2013). Changes in rainfall are also a key apprehension for India due to the fact that river run-off in India is mainly depends on the monsoon rain and more than 50% of the population is engaged in agriculture and allied livelihood activities that depend on rain. Therefore, the variability in rainfall, number of rainy days and percentage share of monthly rain to annual rainfall (Naidu et al. 1999; Dash and Hunt 2007; Guhathakurta and Rajeevan 2008; Ghosh et al. 2009; Pal and Al-Tabbaa 2009; Bhutiyani et al. 2010; Kumar et al. 2010; Kumar and Jain 2011; Pal and Al-Tabbaa 2011; Rana et al. 2012; Ratna 2012; Jain and Kumar 2012; Jhajharia et al. 2012; Dash et al. 2013; Babar 2013) are extensively studied in Indian context. Diverse outcomes show both increasing and decreasing trends in the rainfall, and even the magnitude of change indicates regional variations. A significant trend in the amount of rain was not observed at all-India level (Kumar et al. 2010). Guhathakurta and Rajeevan (2008) and Bhutiyani et al. (2010) analysed the pattern of precipitation distribution in the Western Himalaya and found evidence of increasing trend during the pre-monsoon precipitation and decreasing trend in the monsoon precipitation.

The objective of the study was to analyse the annual, seasonal and monthly trend in air temperature (minimum temperature ($T_{\min}$), maximum temperature ($T_{\max}$), mean temperature (T_{mean}), lowest minimum temperature ($L_{\min}$), highest maximum temperature ($H_{\max}$), rainfall and number of rainy days in the upper Beas basin during 1980–2010. In addition, rainfall intensity was also observed to understand its variations.

Study Area

The analysis was carried out for the upper Beas basin up to Pandoh dam (Fig. 1). Beas River is a tributary of Indus River which originates at the Beas Kund near the Rohtang Pass at an altitude of 4085 m above the mean sea level. The length of upper Beas basin up to Pandoh dam is 116 km, and the catchment area is about 5300 sq. km, out of which only 780 km^2 is under permanent snow (BBMB 1988). Amongst its tributaries, Parbati and Sainj Khad Rivers are glacier fed. Some of the major tributaries which join the Beas River above Pandoh dam are as follows: Sabari Nala near Kullu, Pārbati River near Bhuntar, Tirthan and Sainj Rivers near Larji and Bakhli Khad near Pandoh dam. The elevation varies from 802 m near Pandoh dam up to 6600 m along the north-east edge of the Pārbati sub-catchment which is representative of a typical high-rise Himalaya basin.

Materials and Methods

Daily air temperature (T_{min} and T_{max}) in °C and rainfall (in mm) data of Manali and Bhuntar for the period 1980–2010 were obtained from the India Meteorological Department (IMD). Values of lowest minimum temperature ($L_{\min}$) and highest maximum temperature ($H_{\max}$) in all the months for Manali and Bhuntar were carved out from the daily temperature data. Standard normals of air temperature ($T_{\min,}$ $T_{\max}$ and T_{mean}) and rainfall of Manali and Bhuntar were taken from the IMD Climatological Tables, 1961–1990 (IMD 2010). For better understanding of the trends in temperature, anomalies of annual mean temperature ($T_{\min,}$ $T_{\max}$ and T_{mean}) were computed using standard normals of reference period annual temperature ($T_{\min,}$ $T_{\max}$ and T_{mean}). Formula is given below:

$$T_{\text{ano}} = T_{c.\text{yr}} - T_{\text{nor}}$$

Where T_{ano}—anomaly in annual temperature, $T_{c.\text{yr}}$—annual temperature of the current year and T_{nor} normal temperature of the reference period

The percentage departures in the annual rainfall were computed as follows.

$$\frac{\text{Annual rainfall of the current year} - \text{normal annual rainfall of the reference period}}{\text{Normal annual rainfall of the reference period}} \times 100$$

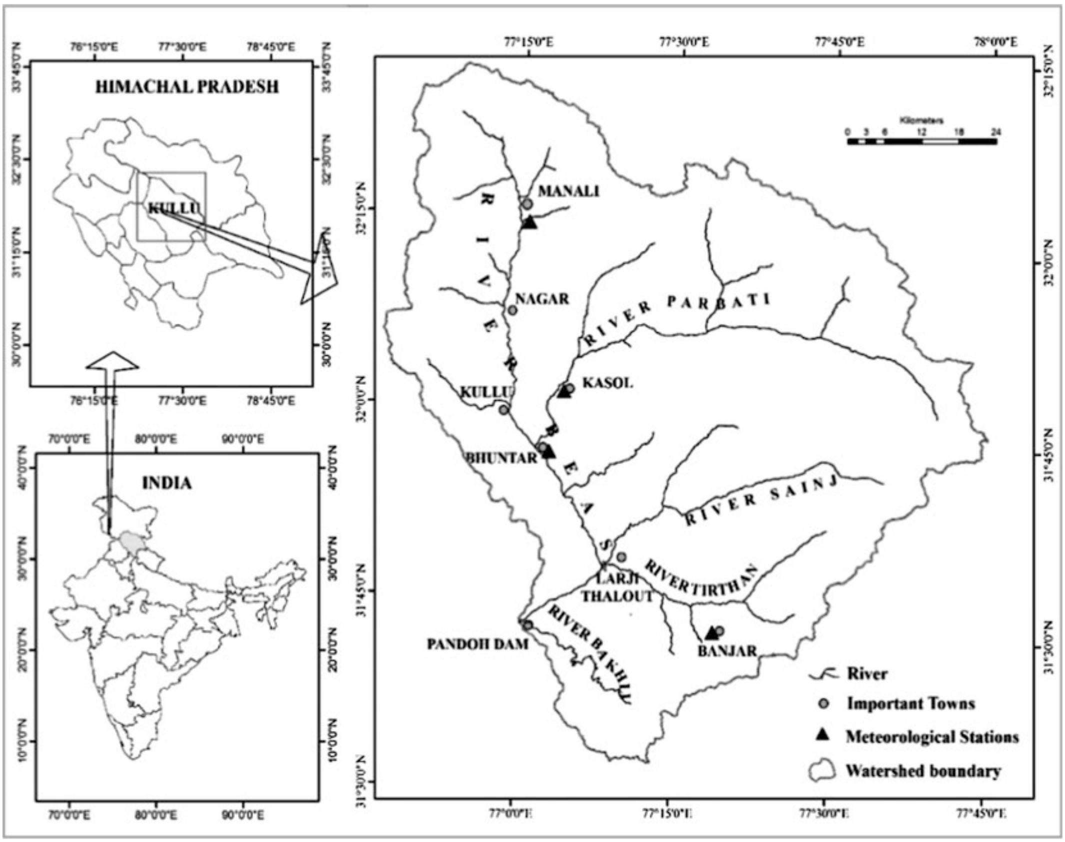

Fig. 1 Location of the upper Beas basin (up to Pandoh dam), Western Himalaya

Interpretation of the percentage departure in annual rainfall was done on the basis of rainfall departure categories defined by IMD.[1] For all the months, the number of days with light (2.5–7.5 mm/day) and moderate rain (7.6–35.5 mm/day) was categorized based on IMD criteria for intensity of rainfall.[2] IMD has given eight categories of intensity of rainfall in India. Out of eight, two above-mentioned categories were chosen for trend analysis because the majority of the rainy days fall under these two categories during the study period. The seasonal dynamics in temperature and rainfall pattern were analysed using a scheme for seasons adapted from a previous study (Jain et al. 2009). The seasons include winter (December to March), pre-monsoon (April to June), monsoon (July to September) and post-monsoon (October and November). Trends in temperature and rainfall data could be identified by using parametric or nonparametric methods, and both the methods are widely used. The present study used the Mann–Kendall and Sen slope's estimator nonparametric tests for computing the trend and its magnitude, respectively, because these methods do not require normality of time series and are less sensitive to outliers and missing values.

Mann–Kendall (MK) nonparametric statistical test was used for analysing the direction of the trend in the climate data. Test, formulated by Mann (1945), as nonparametric test for trend detection and the test statistic distribution has been given by Kendall (1975) for testing nonlinear trend and turning point. Mann–Kendall test is used to identify the monotonic trend in

[1]http://imd.gov.in/section/nhac/wxfaq.pdf.

[2]Ibid.

climatic time series data. The basic assumption is that it does not require the data to be normally distributed. The null hypothesis (H0) in the test assumes that there is no trend (the data are independent and randomly ordered) and this is tested against the alternative hypothesis (H1), which assumes that there is a trend. All data value is compared with all subsequent data values. If a data value from a later time period is higher than a data value from an earlier time period, the statistic S is incremented by 1. If the data value from a later time period is lower than a data value sampled earlier, S is decremented by 1. The net result of all such increments and decrements yields the final value of S. The Mann–Kendall S statistic is computed as follows:

$$S = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} \operatorname{sign}(T_j - T_i)$$

$$\text{Sign}\,(T_j - T_i) = \begin{cases} 1 & if\ Tj - Ti > 0 \\ 0 & if\ Tj - Ti = 0 \\ -1 & if\ Tj - Ti < 0 \end{cases}$$

Where Tj and Ti are the annual values in years j and i, j > i, respectively. A positive value and negative value of S indicate upward and downward trends, respectively. For $n \geq 23$, the statistic S is approximately normally distributed with the mean and variance as follows:

$$E(S) = 0$$

The variance (sd (S)) for the S statistics is given as:

$$\text{sd}\,(S) = \sqrt{\frac{n(n-1)(2n+5) - \sum ti(i)(i-1)(2i+5)}{18}} \quad (1)$$

Where ti denotes the number of ties to extent i. The summation term in the numerator is used only when the data series contains tied values.

The standardized S statistic denoted by Z for an increasing (or decreasing) trend is given as follows:

$$Zs = \begin{cases} \frac{s-1}{\sigma} & \text{for} \quad S > 0 \\ 0 & \text{for} \quad S = 0 \\ \frac{s+1}{\sigma} & \text{for} \quad S < 0 \end{cases}$$

The test statistic Zs is used as a measure of significance of trend. In fact, this test statistic is used to test the null hypothesis, H0. If$|Zs|$ is greater than $Z\alpha/2$, where α represents the chosen significance level (e.g. 5% with Z 0.05 = 1.96), then the null hypothesis is invalid implying that the trend is significant. Mann–Kendall test significance in the present study was tested at 0.05 ($Z = \pm$ 1.96) and 0.01 ($Z = \pm$ 2.58) level of significance.

Theil–Sen's Slope Estimator is used to estimate the direction as well as magnitude of trend. This test is given by Theil (1950) and Sen (1968). This test can be used in cases where the trend can be assumed to be linear. Theil–Sen's trend line is computed with the following equation

$$f\,(t) = Qt + B$$

Where $f\ (t)$ is a continuous increasing (or decreasing) function of time, Q is the slope, and B is a constant.

To get the slope estimate Q in equation, first calculate the slopes (m_{ij}) of all data pairs as follows:

$$m_{ij} = \frac{x_j - x_k}{j - k}\, for\ i = 1,\ 2 \ldots N$$

Where x_j and x_k are data values at time j and k {$j > k$), respectively. If there are n values xj in the time series, we get as many as $N = n\,(n-1)/2$ slope estimates Qi. Order the N pairwise slope estimates, m_{ij} from the smallest to the largest. Determine the Theil–Sen's estimate of slope, Q, as the median value of this set of N ordered slopes. Computation of the median slope depends on whether N is even or odd. The median slope is computed using the following algorithm

$$Q = \begin{cases} m_{(N+1)/2} & \text{if} \quad N = \text{odd} \\ \left(m_{N/2} + m_{(N+2)/2}\right)/2 & \text{if} \quad N = \text{even} \end{cases}$$

A positive value of Q indicates an upward (increasing) trend, and a negative value indicates a downward (decreasing) trend in the time series.

Results and Discussion

Anomalies and Trends in Air Temperature

Anomalies in Temperature

The anomalies of air temperature ($T_{min,}$ T_{max} and T_{mean}) and their trends were determined for Manali and Bhuntar at annual scales for better understanding of the observed trends for the period 1980–2010. Manali and Bhuntar experienced an annual mean T_{min} of 6.6 °C and 10.1 °C, respectively, during 1980–2010. It is observed from Fig. 2b that prior to 2001, both positive and negative anomalies were prominent in the annual mean T_{min} at Manali and Bhuntar but subsequently, positive anomalies are continuous till 2010. Highest and lowest anomalies at Manali in the annual mean T_{min} were observed as 2.2 °C (2006) and 1.2 °C (2000). Annual mean T_{min} at Manali demonstrated a rise of 0.4 °C during 1980–2010, with respect to normal annual T_{min} of reference period. This indicates that the night temperature increased at Manali during the study period. Figure 2b further shows that anomaly in annual mean T_{min} at Bhuntar ranged between −0.74 °C (1987) and 0.9 °C (2006). Compared to Manali, Bhuntar experienced a steady annual mean T_{min} during the study period. Overall, a rise of 0.03^0 C in the annual mean T_{min} was observed at Bhuntar in relation to normal annual T_{min} of the reference period.

Manali experienced annual mean T_{max} of 19.7 °C during 1980–2010. It varied from 16.8 °C (1991) to 20.9 °C (1999) during the period of study (Fig. 3a). A fall of about −0.59 °C was observed in annual mean T_{max} at Manali during 1980–2010 in relation to normal annual T_{max} (Fig. 3b). The annual T_{max} observed at Bhuntar during the same period was 25.4 °C which was nearly 4.5 °C higher than the annual mean T_{max} of Manali. It indicates that Bhuntar experienced higher daytime temperature than Manali. It is because of the location of both the stations (Fig. 1). The annual mean T_{max} at Bhuntar varies from 24 °C in 1982 to 26.8 °C in 2009 during the period of analysis (Fig. 3a). Figure 3b shows higher fluctuations in annual mean T_{max} at Bhuntar during 1980–2010 and ranged between −1.44 °C (1997) and 1.36 °C (2009). Anomalies in annual mean T_{max} became positive after 2006 that indicates a warming trend at Bhuntar. Bhuntar also experienced a slight fall of −0.07 °C in the annual mean T_{max} compared to normal annual T_{max} of reference period.

Manali and Bhuntar experienced an annual T_{mean} of 13.1 °C and 17.8 °C, respectively, during 1980–2010 Fig. 4a. Figure 4b shows that Manali experienced a continuous negative anomaly in annual T_{mean} during 1989–1993, and these became positive since 2001. It means that Manali moved towards the warmer conditions during the last decade, though overall a fall of −0.2 °C in the annual T_{mean} (compared to normal annual T_{mean}) was observed during the period 1980–2010. The latter may be attributed to the high decline in the annual mean T_{max} of about −0.59 °C (Fig. 3b) and the minor rise in the annual mean T_{min} of around 0.4 °C during 1980–2010 (Fig. 2b). Figure 4b shows more negative anomalies at Bhuntar before 1998 but after that anomalies became positive till 2004. After a sudden negative anomaly in 2005, positive anomalies became prominent till 2010. Anomalies in annual T_{mean} at Bhuntar ranged between −1 °C in 1983 and 0.087 °C in 2007 during the study period. A fall of about −0.02 °C was observed in the annual T_{mean} (compared to normal annual T_{mean}) at Bhuntar during 1980–2000. This is probably because of a minor rise of 0.03 °C in annual mean T_{min}(Fig. 2b) and high fall of −0.07 °C in the annual mean T_{max}(Fig. 3b) during 1980–2010.

Annual Trends in Temperature

Annual mean T_{min} at Manali showed a significant increasing trend at the rate of 0.05 °C/year during 1980–2010 (Table 1). This is consistent with

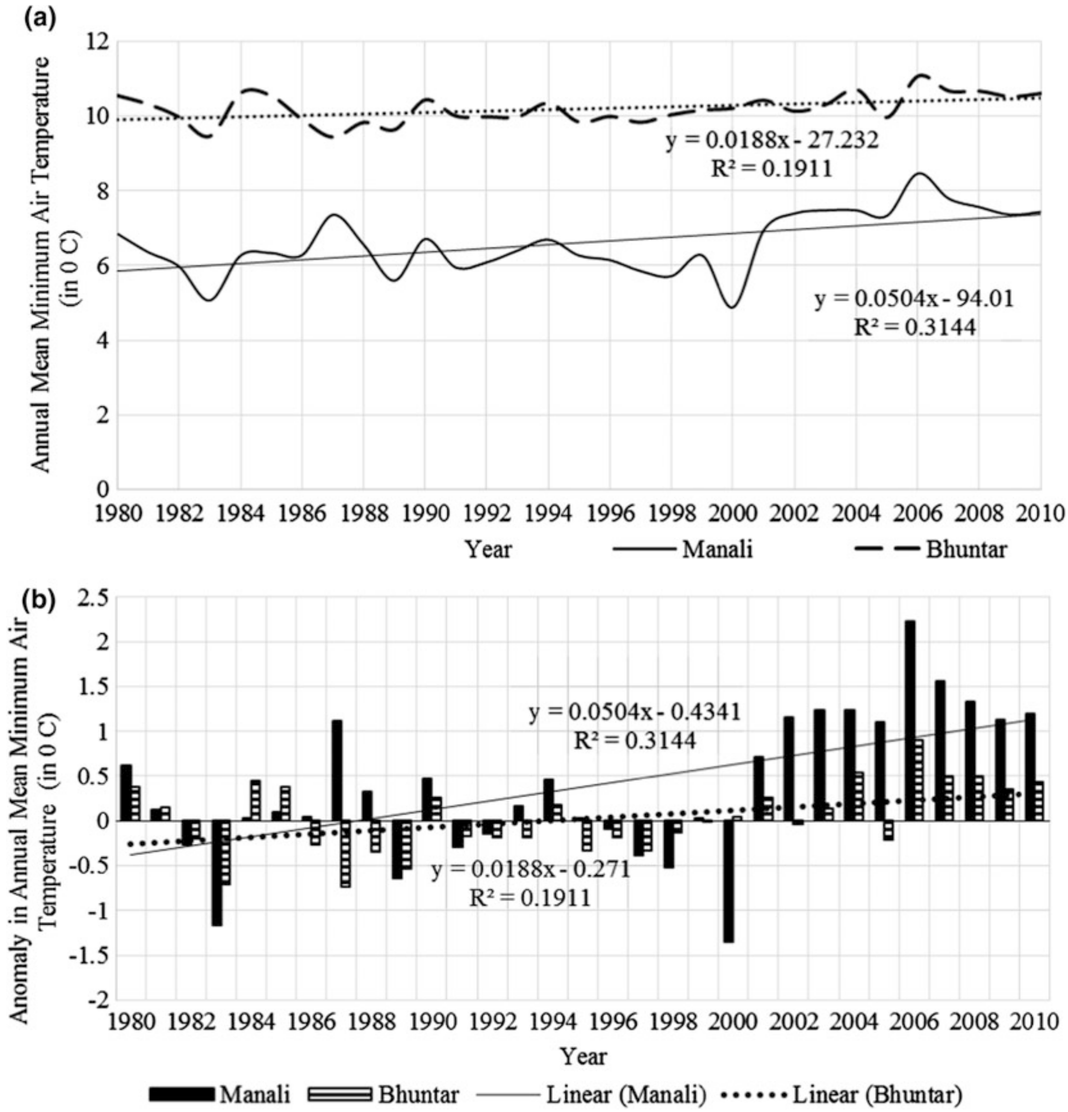

Fig. 2 Trend (**a**) and anomalies (**b**) in annual mean minimum air temperature

the study of Pal and Al-Tabbaa (2010) who found a significant increasing trend in annual mean T_{min} in the Western Himalaya. A similar trend in annual mean T_{min} was also observed at Bhuntar with the rate of about 0.02 °C/year (Table 1) that is slightly lower than the observed trend rate in the annual mean T_{min} at Manali during same period (Table 1).

Results of trend analysis show no trend in the annual mean T_{max} at Manali during the period of analysis (Table 2), though a statistically significant increasing trend was found in the annual mean T_{max} at Bhuntar at the rate of 0.06 °C/year. Dimri and Dash (2012) and Pal and Al-Tabbaa (2009) also observed a rise in annual mean T_{max} in the Western Himalaya. The present study shows that night-time temperature at Manali has gone up though daytime temperature remained stable. On the other hand, daytime temperature at Bhuntar has increased faster than night-time

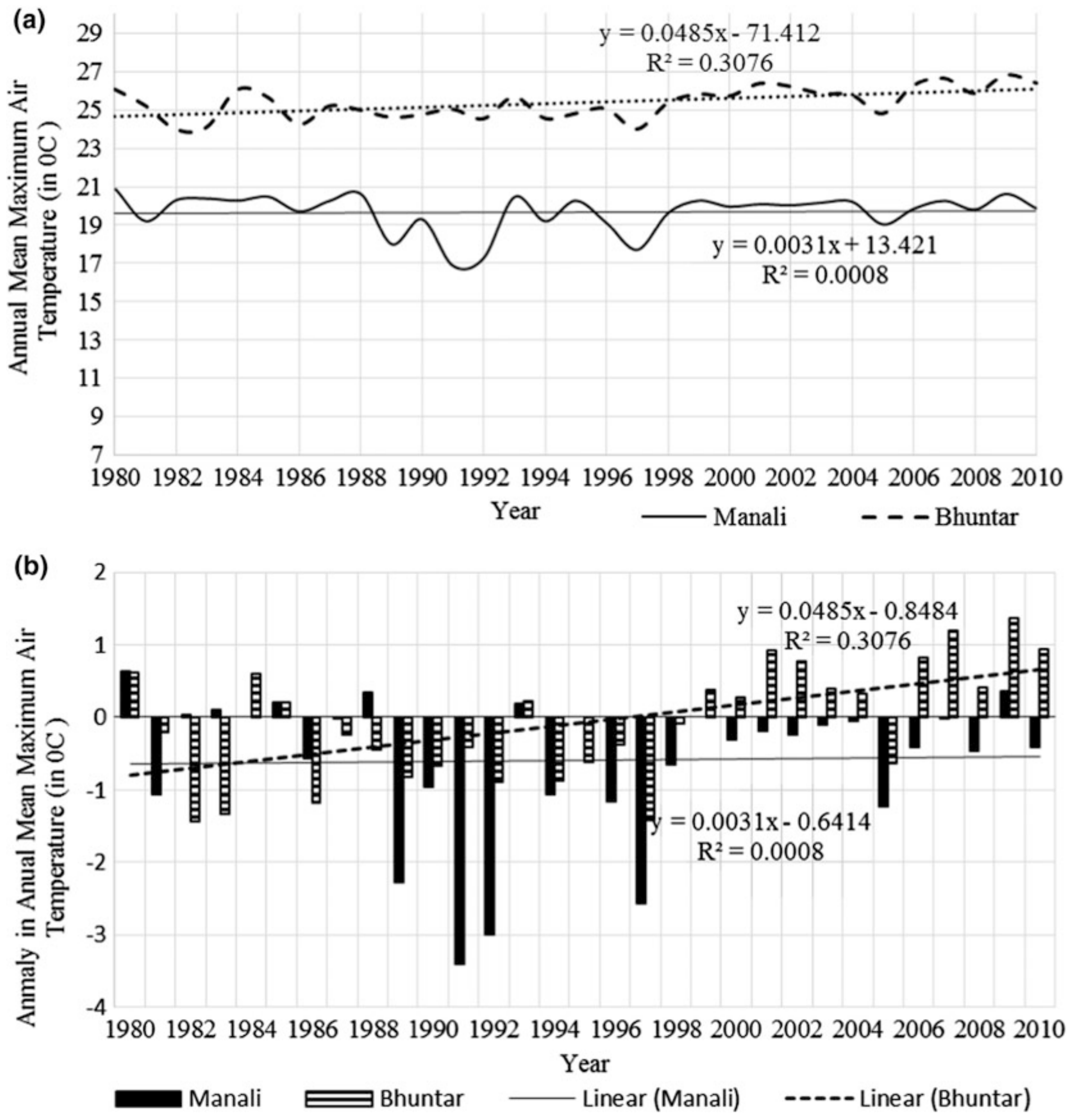

Fig. 3 Trend (**a**) and anomalies (**b**) in annual mean maximum air temperature

temperature during 1980–2010. This is an indication of the albedo changes in the region, which might have caused by the changes in land cover conditions. There are continuous changes from a vegetative to non-vegetative cover in this region.

Annual T_{mean} of Manali showed a rising trend at the rate of 0.03°C/year during 1980–2010 (Table 3). Annual mean T_{min} of the station showed an increasing trend while T_{max} remained stable. Therefore, the observed increase in annual T_{mean} at Manali is primarily due to the increase in annual mean T_{min}. Bhuntar also showed a statistically significant increasing trend in annual T_{mean} at rate of 0.05 °C/year during the period of analysis. The observed increase in annual T_{mean} at Bhuntar is mainly due to the increase in annual mean T_{max} because rising rate in annual mean T_{max} was higher than the annual mean T_{min}. Observed trend in annual T_{mean} is consistent with study of Bhutiyani et al. (2007) who also found a warming trend over the north-west Indian Himalaya during the last century.

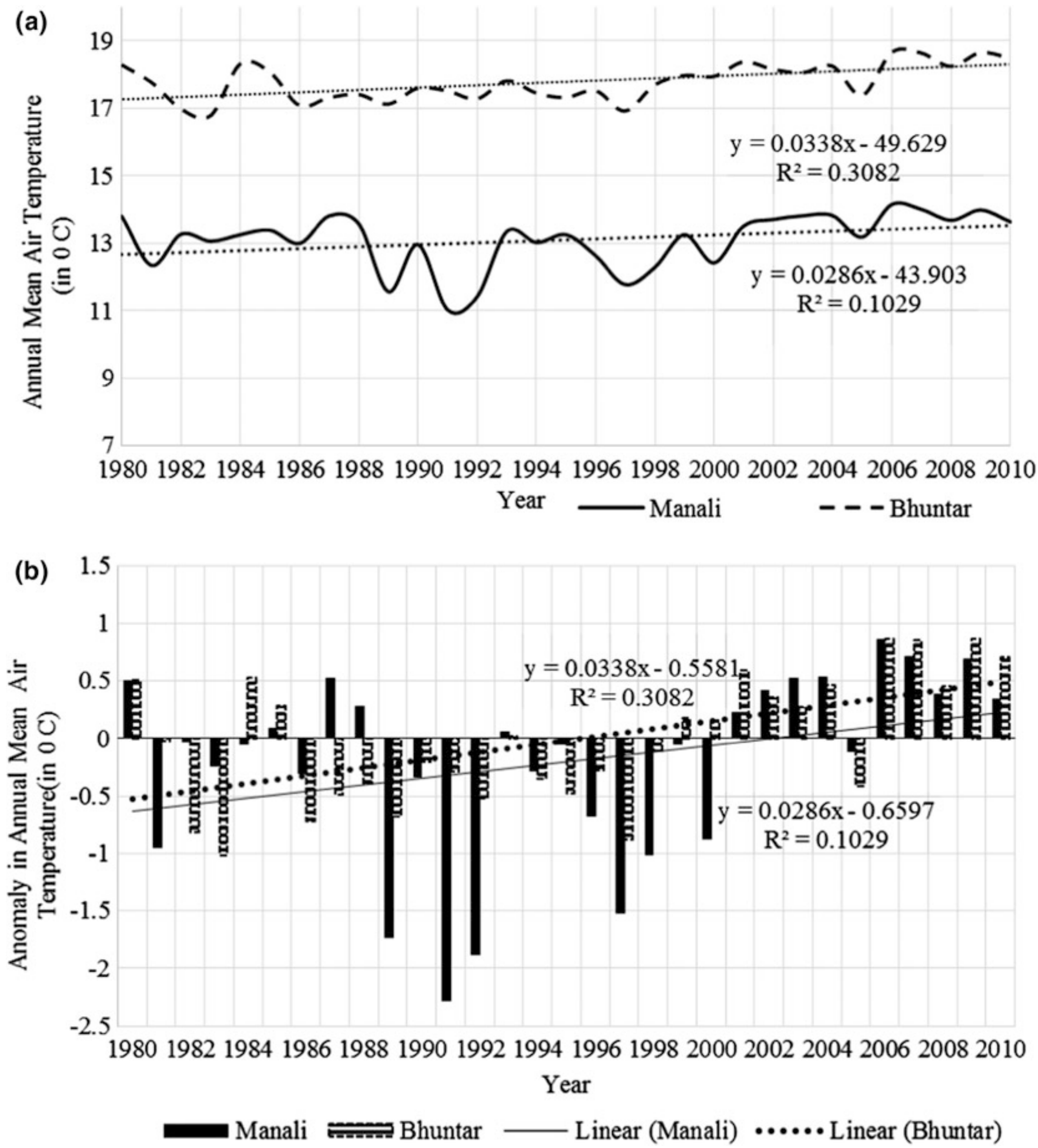

Fig. 4 Trend **a** and anomalies **b** in annual mean air temperature

Seasonal Trends of Temperature

To ascertain whether the warming trend is uniform across seasonal temperature, trends were computed for Manali and Bhuntar for the period 1980–2010. Table 1 shows that mean T_{min} at Manali during winter, pre-monsoon, monsoon and post-monsoon seasons was 0.3, 9.2, 14.3 and 3.6 °C, respectively, during 1980–2010. Trend analysis results of Manali revealed a significant increasing trend in mean T_{min} in all the seasons except monsoon. Highest change in mean T_{min} was observed in the post-monsoon season (0.09 °C/year) followed by the winter season (0.06 °C/year) and pre-monsoon (0.05 °C/year). Bhuntar experienced a mean T_{min} of 3.39, 12.97, 18.52 and 7.17 °C during winter, pre-monsoon, monsoon and post-monsoon seasons, respectively, during 1980–2010 (Table 1). Significant

Table 1 Trend of mean minimum air temperature

Timescale	Manali			Bhuntar		
	Mean (°C)	MK test (Z)	Sen's slope (°C/yr)	Mean (°C)	MK test (Z)	Sen's slope (°C/yr)
Jan	−1.4	**2.04***	**0.04***	1.7	−0.07	0.00
Feb	0.1	1.59	0.03	3.7	1.22	0.02
Mar	2.7	**3.24****	**0.09****	6.6	1.80	0.03
Apr	6.2	1.61	0.05	9.6	**2.53***	**0.04***
May	9.0	1.80	0.05	12.8	1.75	0.05
Jun	12.5	1.59	0.03	16.6	0.51	0.01
Jul	15.5	−0.15	0.00	19.6	1.33	0.02
Aug	15.7	0.94	0.02	19.6	0.41	0.01
Sep	11.7	1.82	0.06	16.4	0.58	0.02
Oct	5.5	**4.48****	**0.10****	9.8	1.19	0.02
Nov	1.8	**4.15****	**0.09****	4.6	0.22	0.00
Dec	−0.04	**3.39****	**0.07****	1.7	−0.92	−0.02
Winter	0.3	**2.96****	**0.06****	3.39	0.27	0.00
Pre-monsoon	9.2	**2.11***	**0.05***	12.97	**1.97***	**0.04***
Monsoon	14.3	1.74	0.03	18.52	1.63	0.02
Post-monsoon	3.6	**4.37****	**0.09****	7.17	0.71	0.01
Annual	6.6	**2.77****	**0.05****	10.2	**2.41***	**0.02***

Significant at 0.01** level and 0.05* level

increasing trend in mean T_{min} at the station was found only during the pre-monsoon season at the rate of 0.04^0 C/year (Table 1) that is slightly lower than the magnitude of change in mean T_{min} of pre-monsoon, observed at Manali. Pal and Al-Tabbaa (2011) also found a rising trend in the mean T_{min} during winter, pre-monsoon and post-monsoon seasons in the Western Himalaya.

Mean T_{max} at Manali during winter, pre-monsoon, monsoon and post-monsoon seasons was 12.9, 23.7, 25 and 19.3 °C, respectively, during the period 1980–2010 (Table 2). The seasonal trend analysis at Manali shows a statistically significant decreasing trend in mean T_{max} during monsoon at the rate of −0.03 °C/year. Broadly, results show that daytime temperature at Manali has gone down during monsoon season while the night temperature remained stable in the same season during the period of analysis. This is inconsistent with the studies of Dash et al. (2007) and Pal and Al-Tabbaa (2010) who found an increase in mean T_{max} of winter season in the Western Himalaya. This is probably due to difference in period of study between the present and above two studies. At Bhuntar, the observed mean T_{max} in the winter, pre-monsoon, monsoon and post-monsoon seasons was 18, 30, 30.7 and 25.3 °C during 1980–2010 (Table 2). Seasonal trend analysis of Bhuntar shows a significant increasing trend in the mean T_{max} during winter at the rate of 0.12 °C/year (Table 2).

At Manali, winter season shows a significant increasing trend in T_{mean} at the rate of 0.04 °C/year during the period of study (Table 3). Since the mean T_{max} of the season remained the same, the above can be attributed to increase in the mean T_{min}. Broadly, mean T_{min} at Manali shows high intra-seasonal variability compared to mean T_{max} during the period of analysis. Significant rising trend in T_{mean} was found at Bhuntar during winter (0.05 °C/year), followed by the pre-monsoon (0.04 °C/year) and post-monsoon (0.03 °C/year) seasons of the period 1980–2010 (Table 3). Results suggest that

Table 2 Trend of mean maximum air temperature

Timescale	Manali			Bhuntar		
	Mean (°C)	MK test (Z)	Sen's slope (°C/yr)	Mean (°C)	MK test (Z)	Sen's slope (°C/yr)
Jan	10.5	0.05	0.00	15.7	**2.21***	**0.08***
Feb	11.8	−0.24	0.00	17.4	**2.58****	**0.11****
Mar	15.8	1.68	0.05	21.3	**3.37****	**0.20****
Apr	20.4	−0.55	0.00	26.6	**2.72****	**0.12****
May	24.3	−0.05	0.00	30.6	0.88	0.04
Jun	26.3	−1.81	−0.05	32.6	−0.44	−0.02
Jul	25.7	−0.70	−0.01	31.3	0.48	0.01
Aug	25.0	−1.38	−0.02	30.7	−0.60	−0.02
Sep	24.4	**−2.43***	**−0.05***	30.0	**−1.97***	**−0.04***
Oct	21.4	−1.07	−0.01	27.7	0.78	0.02
Nov	17.3	−1.45	−0.03	22.9	0.70	0.02
Dec	13.4	−0.64	−0.01	17.7	1.22	0.04
Winter	12.9	1.23	0.02	18.0	**4.22****	**0.12****
Pre-monsoon	23.7	−0.53	−0.01	30.0	1.87	0.07
Monsoon	25.0	**−2.52***	**−0.03***	30.7	−0.82	−0.02
Post-monsoon	19.3	−1.79	−0.01	25.3	0.99	0.02
Annual	19.7	−0.77	-0.01	25.4	**3.30****	**0.06****

Significant at 0.01** level and 0.05* level

the significant changes in T_{mean} occurring during the winter at Bhuntar had the major influence of the variations in winter season mean $T_{\max}$ because mean $T_{\min}$ of winter showed no trend during the study period.

Monthly Trends of Temperature

Mean $T_{\min}$ of Manali ranged between −1.4 °C in January and 15.7 °C in August during 1980–2010 (Table 1). Table 1 indicates that $T_{\min}$ of January, March, October, November and December was rising at Manali during the period of analysis. Highest and lowest change in mean $T_{\min}$ was found in October (0.1 °C/year) and January (0.04 °C/year), respectively. $T_{\min}$ at Bhuntar varies from 1.7 °C (December and January) to 19.6 °C (July and August) during the period of analysis which was much higher than Manali because of altitudinal variation (Table 1). The monthly trend analysis shows a significant increasing trend in mean $T_{\min}$ of April (0.04 °C/year) during 1980–2010 (Table 1). It indicates that Bhuntar experienced less variations in the monthly mean $T_{\min}$ compared to Manali (Table 1) during the same period of observation.

$T_{\max}$ at Manali varies from 10.5 °C in January to 26.3 °C in June during 1980–2010 (Table 2). Trend analysis at Manali showed a statistically significant decreasing trend $T_{\max}$ in September at the rate of −0.05 °C/year (Table 2). Overall, trend analysis of monthly mean $T_{\min}$ and $T_{\max}$ at Manali indicates more warming trend during the night temperature of winter months while the daytime temperature in the monsoon month shows a decline. Moreover, magnitude of change of monthly mean $T_{\min}$ was higher than the monthly mean $T_{\max}$. Monthly mean T_{max} in Bhuntar varies from 15.7 °C in January to 32.6 °C in June during 1980–2010 (Table 2). Table 2 shows a significant increasing trend at Bhuntar in mean $T_{\max}$ of March (0.20 °C/year) followed by April (0.12 °C/year), February (0.11 °C/year)

Table 3 Trend of mean air temperature

Timescale	Manali			Bhuntar		
	Mean (°C)	MK test (Z)	Sen's slope (°C/yr)	Mean (°C)	MK test (Z)	Sen's slope (°C/yr)
Jan	4.6	0.89	0.00	8.7	**2.35***	**0.05***
Feb	5.8	0.80	0.02	10.4	1.77	0.05
Mar	9.2	**2.55***	**0.08***	13.7	**2.65****	**0.10****
Apr	13.1	0.14	0.00	18.0	**2.48***	**0.07***
May	16.6	1.04	0.02	21.6	1.02	0.03
Jun	19.3	−0.84	-0.01	24.6	0.20	0.01
Jul	20.5	0.09	0.00	25.4	0.85	0.02
Aug	20.2	0.63	0.00	25.2	−0.03	0.00
Sep	18.0	−0.46	0.00	23.2	−0.41	−0.01
Oct	13.5	1.50	0.02	19.0	**2.11***	**0.03***
Nov	9.5	0.67	0.00	13.8	1.89	0.03
Dec	6.7	0.51	0.00	9.8	0.95	0.01
Winter	6.6	**2.41***	**0.04***	10.7	**3.50****	**0.05****
Pre-monsoon	16.3	1.95	0.03	21.4	**2.11***	**0.04***
Monsoon	19.6	0.21	0.00	24.6	0.17	0.00
Post-monsoon	11.5	1.63	0.02	16.4	**2.48***	**0.03***
Annual	13.1	**2.12***	**0.03***	17.8	**3.38****	**0.05****

Significant at 0.01** level and 0.05* level

and January (0.08 °C/year). On the other hand, September shows a significant decreasing trend in T_{max} (0.04 °C/year). It shows that variations in mean T_{max} of winter months were higher than other months at Bhuntar during the period of analysis.

T_{mean} of Manali ranged between 4.6 °C in January and 20.5 °C in July during the period 1980–2010 (Table 3). T_{mean} of March showed a statistically significant increasing trend at the rate of 0.08 °C/year. The rise in T_{mean} of March may be attributed to the rise in the mean T_{min} as mean T_{max} of the month shows no trend during the study period. At Bhuntar, T_{mean} varies from 8.7 °C in January to 25.4 °C in June during the period 1980–2010 (Table 3). T_{mean} at Bhuntar shows a significant rising trend in January, March, April and October during the period of analysis. Highest change in T_{mean} was found in the March (0.10 °C/year) followed by April (0.07 °C/year), January (0.05 °C/year) and October (0.03 °C/year). Trend analysis results further show that change in T_{mean} of January and March may be attributed to the rising trend in mean T_{max} of the respective months as mean T_{min} of the months remained stable during the period of analysis. Furthermore, both mean T_{min} and T_{max} of October show a rising trend, but the highest change was found in mean T_{max}. Therefore, the observed increase in T_{mean} of October is primarily due to the increase in mean T_{max} of the month.

Trend analysis results of L_{min} and H_{max} of Manali and Bhuntar are shown in Table 4. It shows a significant rising trend in L_{min} at Manali in February, April, May and November. Highest magnitude of change was found in April followed by May, November and February. A significant rise in mean T_{min} of November at Manali (Table 2) had the influence on significant rising trend in L_{min} of the month during the study period. Furthermore, Table 4 shows a significant fall in H_{max} in September and December at Manali with the highest decline in the former month during 1980–2010. September also had a

Table 4 Trend in lowest minimum (L_{min}) and highest maximum temperature (H_{max})

Months	Manali		Bhuntar	
	L_{min} (°C/year)	H_{max} (°C/year)	L_{min} (°C/year)	H_{max} (°C/year)
Jan	0.325	−0.12	−0.075	0.269
Feb	**0.419***	0.13	0.061	**0.490****
Mar	0.351	0.358	**0.390***	**0.543****
Apr	**0.731****	-0.144	0.26	**0.453***
May	**0.437***	0.01	0.35	0.238
Jun	0.247	−0.363	0.268	0.171
Jul	0.172	−0.374	**0.544****	−0.037
Aug	0.224	−0.361	0.269	−0.13
Sep	0.066	**−0.546****	0.331	−0.133
Oct	0.396	−0.177	0.259	**0.379***
Nov	**0.435***	−0.136	-0.065	0.282
Dec	0.397	**−0.537****	-0.091	0.178

Significant at 0.01** level and 0.05* level

significant decline in mean T_{max} during the study period (Table 2). This may be because of a significant fall in H_{max} in the month over the period. At Bhuntar, L_{min} showed a significant increasing trend in March and July during the period of analysis. In contrast, H_{max} shows a significant rise in most of the winter months. Highest changes were found in March followed by February, April and October. Mean T_{max} of February, March and April showed a statistically significant rising trend at Bhuntar during 1980–2010. Therefore, the observed increase in H_{max} might be influencing the increase in mean T_{max} of the mentioned months.

Manali and Bhuntar experienced a warming trend during 1980–2010. This may be attributed to increase in anthropogenic activities such as, land use/land cover changes, tourism, and construction. Manali is a destination for tourists from all over the world. According to Census of India (2011), Manali and Bhuntar experienced a growth rate of 252 and 62%, respectively, during 1981–2011. It has registered the highest growth rate amongst urban centres in the state during 1991–2001. During the decade 1991–2001, Manali has registered an unprecedented growth rate of 157.50% that was higher amongst the urban centres in Himachal Pradesh that means Manali has attracted a substantial number of people during this decade in addition to natural growth. During the same decade, Bhuntar has also experienced high population growth of 43.3%. Consequently, over the time, residential area, commercial spaces, transport network, etc., have increased at both stations that led to changes in land cover over the years. Rising vehicular population and industries leads to rise in aerosol which influenced the air temperature at both the stations. Acharya and Sreekesh (2013) found consistent low optical depth (<0.6 at both 0.47 and 0.66 µm) in the area in January, April and October during 2001–2009 which are also the months in which both stations show maximum variations in T_{min}, T_{max} and T_{mean}.

Trends in Rainfall and Rainy Days

Manali experienced a mean annual rainfall of 1091 mm during 1980–2010 (Table 5). Highest and lowest annual rainfall at Manali was 2000 mm (1995) and 429 mm (1992), respectively (Fig. 5). The percentage departure in the annual rainfall from the normal shows that Manali experienced excess rain only in 5 years while 17 years had deficient rain during the study period (Fig. 5). Overall, a fall of about 53 mm was observed at Manali in annual rainfall in

Table 5 Trend in monthly rainfall

Timescale	Manali			Bhuntar		
	Mean (mm)	MK test (Z)	Sen's slope (mm/yr)	Mean (mm)	MK test (Z)	Sen's slope (mm/yr)
Jan	73	−0.20	-0.22	77	−0.27	−0.30
Feb	96	**−2.36***	**−3.73***	109	0.04	0.08
Mar	151	**−2.47***	**−4.95***	134	−1.75	−2.15
Apr	108	−1.78	−2.10	80	−1.59	−1.48
May	80	−1.36	−1.31	70	−1.04	−0.82
Jun	79	−0.18	−0.23	53	0.52	0.30
Jul	180	**−2.05***	**−4.36***	129	0.04	0.12
Aug	174	−0.01	0	111	1.02	1.04
Sep	93	0.43	0.38	72	1.57	1.67
Oct	35	−0.54	−0.05	31	−0.97	−0.26
Nov	29	−0.57	−0.05	21	0.00	0.00
Dec	55	−1.80	−1.71	39	−1.17	−0.46
Winter	380	**−2.57***	**−8.55***	359	−0.79	−3.00
Pre-monsoon	276	−1.20	−2.56	202	−1.37	−1.53
Monsoon	456	−0.80	−3.16	312	1.75	3.56
Post-monsoon	66	−0.86	−0.82	60	−1.25	−1.23
Annual	1091	−0.78	−7.8	926	−0.87	−3.26

Significant at 0.01** level and 0.05* level

relation to normal during the period. During the same period, Bhuntar received relatively less mean annual rainfall of 926 mm (Table 5). The percentage departure in the annual rainfall from the normal (Fig. 6) shows that Bhuntar received excess rain in 1982, 1988, 1998 and deficient rain in 1980, 1984, 2002 and 2009.

It shows that years of deficient rain at Bhuntar exceed the years of excess rain during 1980–2009. However, a rise of 9 mm was found in the mean annual rainfall of Bhuntar (relative to the normal annual rainfall) during the period of analysis. It was found that the amount of excess rain occurred at Bhuntar was more than the amount of deficient rain during the study period. Therefore, slight rise in mean annual rainfall at Bhuntar is primarily due to the increase in amount of excess rainfall.

Annual Trend of Rainfall and Rainy Days

The annual trend analysis indicates no significant trend in the annual rainfall of Manali and Bhuntar during 1980–2010 (Table 5). Manali had a marginally significant decreasing trend in the annual number of rainy days at the rate of −0.6 days/year during the study period (Table 6). It indicates that Manali received almost same amount of rainfall in less days, which means rainfall intensity had slightly increased over the period. Bhuntar experienced no trend in the annual number of rainy days over the period (Table 6).

Seasonal Trend of Rainfall and Rainy Days

Table 5 indicates that Manali received highest rainfall in the monsoon season (41%) followed by winter (35%), pre-monsoon (25%) and post-monsoon (6%) seasons. The trend analysis of seasonal rainfall shows a significant decreasing trend during the winter season at the rate of −8.55 mm/year (Table 5). This trend is in contrast to the study done by Kumar et al. (2010) who found a decreasing trend in the monsoon

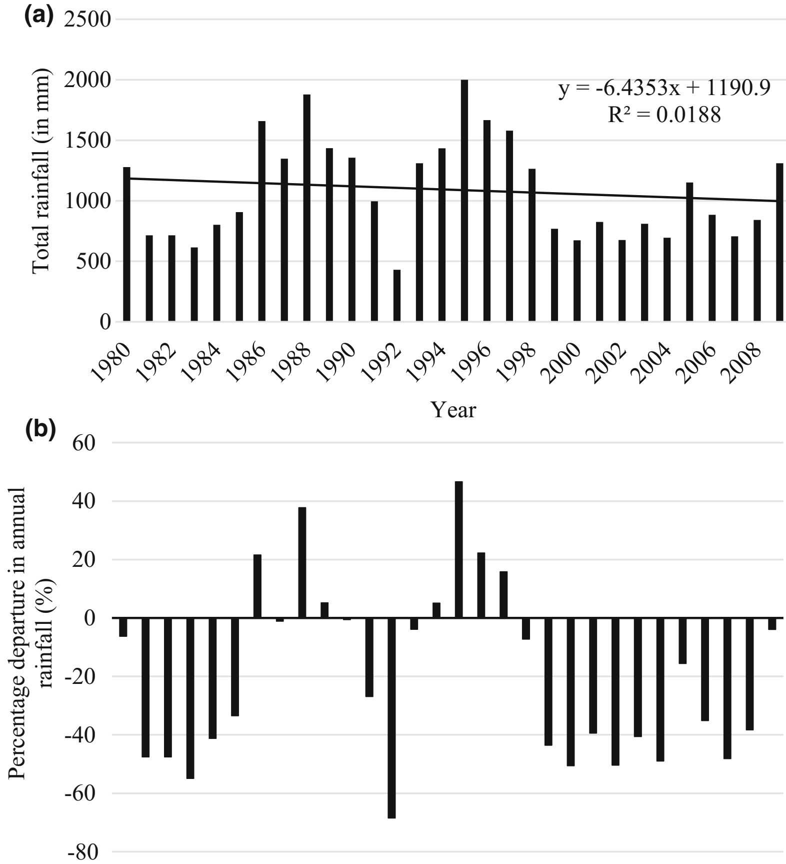

Fig. 5 Annual rainfall, its trend **a** and percentage departure **b** at Manali

rainfall and increasing trend during the pre-monsoon, post-monsoon and winter rainfall at the national scale. A decreasing trend in winter rainfall at Manali may result in the decrease of river run-off in the season that would negatively affect the availability of water. Bhuntar received the relatively highest rain during winter (39%) followed by monsoon (34%), pre-monsoon (22%) and post-monsoon (7%) seasons (Table 5). The trend analysis of rainfall at Bhuntar shows no trend in the seasons during 1980–2009 (Table 5).

Manali experienced the highest number of rainy days during monsoon season followed by winter, pre-monsoon and post-monsoon seasons (Table 6). The seasonal trend analysis shows a significant decreasing trend during winter and monsoon in the number of rainy days at the rate of −0.42 day/year and −0.39 day/year, respectively, during the study period (Table 6). This might be the cause for reduction in the amount of rainfall during the season at Manali (Table 5). If this trend continues, it may adversely impact the water availability conditions in the region. The observed mean number of rainy days at Bhuntar in the winter, pre-monsoon, monsoon and post-monsoon was 23, 20, 24 and 3, respectively, during 1980–2009 (Table 6). Results of Bhuntar showed a significant increasing trend in the number of rainy days at the rate of 0.03/year during monsoon (Table 6). However, the amount of rainfall was stable at the station (Table 5), indicating the possibility of reduction in the rainfall intensity at the station during the study period.

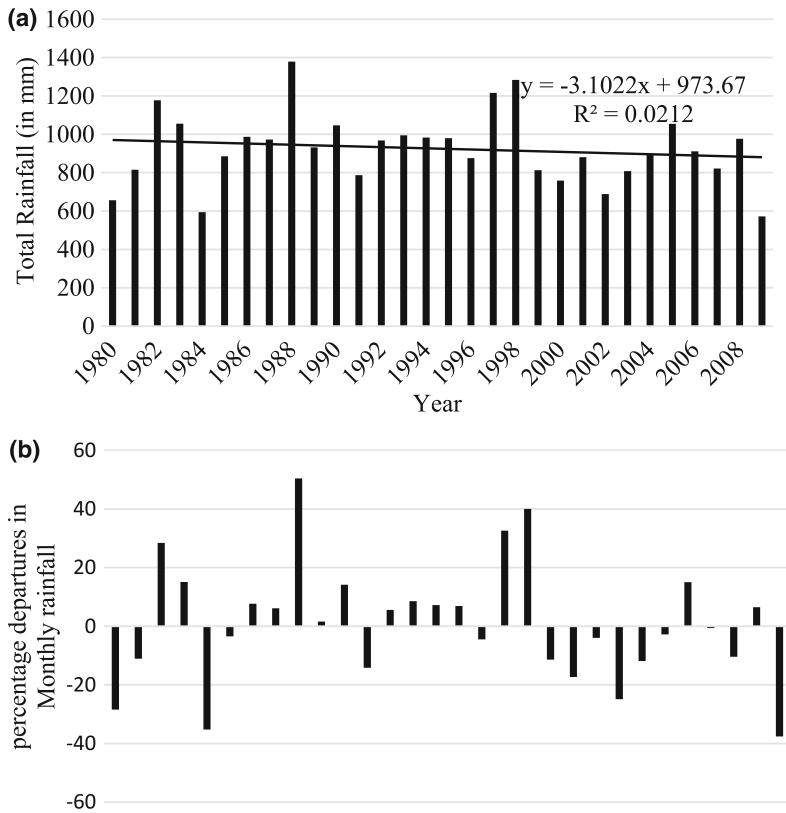

Fig. 6 Annual rainfall, its trend **a** and percentage departure **b** at Bhuntar

Monthly Trends of Rainfall and Rainy Days

Mean monthly rainfall at Manali ranged between 180 mm (July) and 29 mm (November) during 1980–2010 (Table 5). Trend analysis shows a significant decreasing trend in rainfall of February, March and July (Table 5). The highest rate of decrease in rainfall at the station was in March (−4.95 mm/year) followed by July (−4.36 mm/year) and February (−3.73 mm/year). Kumar et al. (2010) found an increasing trend in rainfall of June, July and September and decreasing trend in August at the national scale. Rani (2014) found a significant negative correlation at Manali between the percentage departures of monthly rainfall and anomalies in monthly mean air temperature in March that means an increase in positive anomalies in mean air temperature of March could have resulted in a reduction in rainfall in March. Bhuntar experienced mean monthly rainfall ranged between 134 mm (March) and 21 mm (November) during 1980–2009 (Table 5). Monthly rainfall at Bhuntar shows no significant trend during the period of study.

Average number of rainy days in Manali varied from 2 (November) to 16 (August) (Table 6) during 1980–2010. Trend analysis of the average number of rainy days at Manali shows a significant decreasing trend in February, March and December (Table 6). Rate of decrease in number of rainy days was higher in February followed by March and December. The monthly rainfall of Manali also shows a significant decreasing trend during February and March (Table 5). It indicates that probably decreasing trend in the number of rainy days was responsible for decreasing trend in the amount of rainfall of these months. Average number of rainy days at Bhuntar varied from 2 (October and November) to 9 (July and August) during 1980–2009 (Table 6). Trend analysis at the station shows a

Table 6 Trend in rainy days

Timescale	Manali			Bhuntar		
	Mean (days)	MK test (Z)	Sen's slope (days/yr)	Mean (days)	MK test (Z)	Sen's slope (days/yr)
Jan	6	0.05	0.00	5	0.65	0.00
Feb	8	**−2.85****	**−0.19****	7	0.71	0.00
Mar	9	**−1.96***	**−0.14**	9	−0.90	−0.08
Apr	6	−0.56	0.00	7	−0.86	−0.05
May	7	−0.26	0.00	7	0.18	0.00
Jun	9	1.85	0.14	6	**2.45***	**0.17***
Jul	15	−1.81	−0.22	9	1.33	0.11
Aug	16	−0.55	0.00	9	1.62	0.13
Sep	9	−1.06	−0.09	5	**2.01***	**0.16***
Oct	3	0.36	0.00	2	−0.10	0.00
Nov	2	0.44	0.00	2	0.26	0.00
Dec	3	**−2.22***	**−0.12**	3	−0.71	0.00
Winter	27	**−2.67****	**−0.42****	23	−0.34	0.00
Pre-monsoon	22	0.61	0.06	20	0.79	0.17
Monsoon	40	**−1.99***	**−0.39***	24	**2.17***	**0.36***
Post-monsoon	5	0.22	0.00	3	−0.13	0.00
Annual	94	**−2.05***	**−0.6**	70	0.70	0.33

Significant at 0.01** level and 0.05* level

Table 7 Trend in rainy days under different categories of rainfall intensity

Months	Manali		Bhuntar	
	Light rain (2.5–7.5 mm/day)	Moderate rain (7.6–35.5 mm/day)	Light rain (2.5–7.5 mm/day)	Moderate rain (7.6–35.5 mm/day)
	Sen's slope (days/yr)			
Jan	−0.029	0.064	−0.059	−0.235
Feb	0.123	**−0.434***	−0.136	0.082
Mar	−0.268	−0.028	**−0.371***	−0.26
Apr	−0.068	−0.273	−0.312	−0.289
May	0.191	−0.059	−0.299	**−0.370***
Jun	**0.457***	0.128	0.057	−0.034
Jul	−0.323	−0.153	−0.09	−0.284
Aug	0.186	0.109	−0.047	−0.062
Sep	−0.183	0.001	0.266	0.011
Oct	0.081	−0.149	−0.116	−0.195
Nov	−0.122	−0.037	0.309	−0.177
Dec	−0.233	**−0.385***	−0.035	−0.111

Significant at 0.01** level and 0.05* level significant increasing trend in number of rainy days of June and September at the rate of 0.17 days/year and 0.16 days/year, respectively, during the period of analysis. However, the amount of rainfall in these months was stable (Table 5). It indicates a reduction in the rainfall intensity at the station during the study period.

Trend in Rainfall Intensity

Number of days with light and moderate rain at both stations were categorized in the study to understand their trend and magnitude of change during 1980–2010 (Table 7). Manali experienced a significant increase in days with light rain in June and fall in days with moderate rain in the winter months (February and December) during the study period. Reduction in the days of moderate rainfall intensity in February probably led to decrease in the rainfall of that month at Manali. Bhuntar experienced a significant decreasing in days with light (March) and moderate rain (May) during the period of analysis. Despite this, rainfall was almost stable at Bhuntar during 1980–2010.

Conclusions

The present study was an attempt to understand the annual, seasonal and monthly trends, including the magnitude of the trend in $T_{\min}$, T_{max}, T_{mean}, $L_{\min}$, $H_{\max}$, amount of rainfall, rainy days and rainfall intensity of the upper Beas basin in the Western Indian Himalaya during 1980–2010. The findings show a significant increasing trend in annual mean $T_{\min}$ at Manali. On the other hand, Bhuntar experienced an increasing trend in annual mean $T_{\min}$ and $T_{\max}$ during the period of analysis. The rate of increase in annual mean $T_{\max}$ at the station was higher than that of annual mean $T_{\min}$. Both the stations also showed a rising trend in annual T_{mean} which is in tune with the finding of Bhutiyani et al. (2007). Manali experienced a significantly higher rate of warming compared to Bhuntar. The seasonal trend analysis of Manali showed a rising trend in the mean $T_{\min}$ of all the seasons except monsoon while mean $T_{\max}$ showed a decreasing trend in monsoon. Bhuntar experienced a significant increasing trend in mean $T_{\min}$ and $T_{\max}$ during pre-monsoon and winter season, respectively. Overall, both the stations experienced a significant rising trend in T_{mean} of winter season with maximum change at Bhuntar. During post-monsoon season, also Bhuntar had experienced a rising trend in T_{mean}. The rate of change of seasonal $T_{\min}$ at Manali is higher than that of seasonal $T_{\max}$ and Bhuntar experienced opposite to this pattern during the period 1980–2010. Based on the trend analysis of temperature of two stations, it would be difficult to conclude that the upper Beas basin study had a warming tendency during the assessment period, as there is a need for more stations data that could represent altitudinal variations of the whole basin. The slight warming trend at these stations may be attributed to increasing anthropogenic activities, especially towards the lower reaches of the basin. Intensification of tourism and other economic activities resulted in land use/land cover changes ensuing an increase in built-up area and reduction in vegetative cover. This transformed the albedo of those regions, augmenting the temperature. Rise of tourist activities also increased the vehicular movement in this area, and consequent rise in aerosols might have also contributed to rise in air temperature because of increased trapping efficiency.

In case of annual rainfall, Manali showed no significant trend, though significant reduction was observed in monthly (February, March and July) rainfall during 1980–2010. Bhuntar experienced no trend in annual and monthly rain. In case of seasonal rain, Manali shows a significant decreasing trend during winter. Bhuntar showed no trend in seasonal rain. For number of rainy days, Manali showed a significant decreasing trend in February, March and December. Trend analysis of monthly rainfall and rainy days at Manali showed that the decreasing trend in the number of rainy days was responsible for decreasing trend in the amount of rainfall of February and March. Bhuntar experienced a significant increasing trend in number of rainy days of June and September during the period of analysis. However, the amount of rainfall in these months was stable at Bhuntar. It indicates a reduction in the rainfall intensity at the station during the study period. Therefore, it can be concluded that there are evidences of change in the amount of rainfall and rainy days of the study area with seasonal and monthly variations during the period of analysis. It may influence the hydropower generation and other activities that are directly or indirectly depend on the water availability. The results point to the wider variability in temperature and rainfall implying an increased unpredictability in weather in this area in near future. It may be a precursory indicator of an imminent climate change. So, there is need for wider monitoring of rainfall, considering topography and altitudinal variations, in the upper Beas river basin for proper planning and management.

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The Impact of Extreme Weather Events on Food Security

Tom Beer

Abstract

To meteorologists, food security is dominated by the impacts of weather and climate on food systems, but the link between the atmosphere and food security is more complex. Extreme weather events, the exemplar of which are tropical cyclones, impact directly on agriculture, but they also impact on the logistical distribution of food and can thus disrupt the food supply chain, especially in urban areas. A holistic approach is required to understand the phenomena, to forecast outcomes and to predict their societal consequences. In the Food Security recommendations of the Rio + 20 Forum on Science, Technology and Innovation for Sustainable Development, it states that it is important "To understand fully how to measure, assess and reduce the impacts of production on the natural environment including climate change, recognising that different measures of impact (e.g. water, land, biodiversity, carbon and other greenhouse gases) may trade-off against each other…". The International Union of Geodesy and Geophysics (IUGG), through its Union Commission on Climatic and Environmental Change (CCEC), led a consortium of international scientific unions to examine weather, climate and food security as well as to look at the interaction of food security and geophysical phenomena.

Keywords

Extremes · Disasters · Natural hazards · Food · Food security

Introduction

To meteorologists and climatologists, food security is dominated by the impacts of weather and climate on food systems, and the meteorological

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community has primarily focussed on food production and its disruption during extreme weather events. Extreme weather events, the exemplar of which are tropical cyclones, impact directly not only on agriculture but also on the logistical distribution of food. A pluri-disciplinary approach is required to understand the phenomena, to forecast catastrophic events such as tropical cyclones and to predict their societal consequences, given that past experience indicates that the social consequences of a tropical cyclone in the developed world, disastrous though they may be, are less disastrous than the social consequences of an equivalent disaster in the developing world.

In the Food Security recommendations of the Rio + 20 Forum on Science, Technology and Innovation for Sustainable Development, held as a preparatory scientific meeting to the 2012 UN Conference on Sustainable Development, one of the recommendations states that scientists need "To understand fully how to measure, assess and reduce the impacts of production on the natural environment including climate change, recognising that different measures of impact (e.g. water, land, biodiversity, carbon and other greenhouse gases) may trade-off against each other…".

Safety and Security

Within the risk assessment community, most attention has been paid to issues related to defining risk, evaluating risk and treating risk along with substantial academic investigation related to the concept of uncertainty and how this relates to risk.

Far less attention has been devoted to the epistemological issue of what, exactly, is the antonym of risk. If pressed, most risk analysts would probably say that safety is the opposite of risk, but if then queried about security would consider that safety and security are synonymous.

Australia has an enviable safety record. The national airline, Qantas, has the best safety record of any international airline. The Australian State of Victoria was the first jurisdiction in the world to legislate compulsory seat belts in automobiles. It is compulsory to wear helmets when riding horses, motorcycles or bicycles. When dealing with food, food security is seen as being a much wider concept with food safety being just one small part of food security—as may be seen by examination of Fig. 1.

If we use the Beer and Ziolkowski (1995) definition of risk as: The risk during a given time is the union of a set of likelihoods and a set of consequences of the scenarios under consideration; then risk minimisation of extreme weather events must consist of reducing the consequence. Safety and security relate to minimising the consequences. Developed countries, with greater resources to apply to recovery, rehabilitation and rebuilding, are better able to minimise the consequences than developing countries.

Sendai Framework and IRDR

The Sendai Framework for Disaster Risk Reduction 2015–2030 was adopted at the Third UN World Conference on Disaster Risk Reduction in Sendai, Japan, on 18 March 2015. It aims to achieve a substantial reduction of disaster risk and losses in lives, livelihoods and

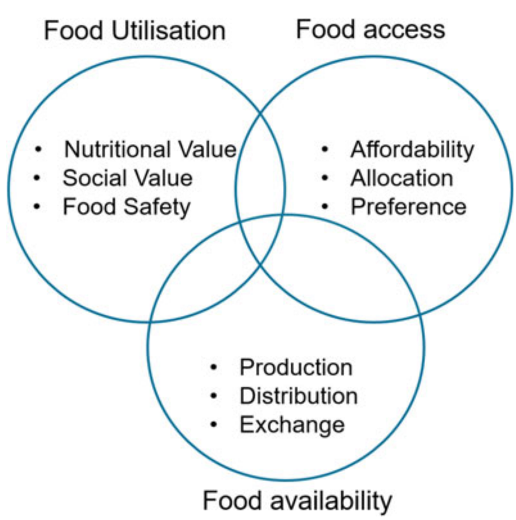

Fig. 1 The research programme future earth envisages food security as being composed of three components—utilisation, access and availability

health and a substantial reduction of losses in the economic, physical, social, cultural and environmental assets of persons, businesses, communities and countries over the next 15 years.

The Framework outlines seven targets and four priorities for action to prevent new and reduce existing disaster risks: (i) Understanding disaster risk; (ii) Strengthening disaster risk governance to manage disaster risk; (iii) Investing in disaster reduction for resilience and; (iv) Enhancing disaster preparedness for effective response, and to "Build Back Better" in recovery, rehabilitation and reconstruction.

The overall expectation is that the scientific community, through the international research programme Integrated Research on Disaster Risk (IRDR), will provide the underpinnings for the first and the last actions of the Sendai Framework. This expectation arises because the three research objectives of IRDR are:

Objective 1	Characterisation of hazards, vulnerability and risk.
Objective 2	Understanding decision-making in complex and changing risk contexts.
Objective 3	Reducing risk and curbing losses through knowledge-based actions.

Rural and Urban Vulnerability to Weather Events

Meteorological variability and extreme weather conditions have increased in frequency in the last century (Porter and Semenov 2005). Figure 2 shows the number of climatological, meteorological, hydrological, geological and biological disasters recorded in the EMDAT database of disaster trends from 1980 to 2016. Extreme and variable weather conditions, such as stronger and more irregular precipitation or increased temperature, lead to significant declines in crop yields and crop stability (Lansigan et al. 2000; Olesen and Bindi 2002; Wollenweber et al. 2003). Unfortunately, despite the extreme impacts of extreme weather conditions on agroecosystems and the broad implications for food supply and production, weather variability and weather extremes are rarely studied outside of rural agroecosystems. Specifically, there is a large gap in research on weather effects, and especially the effects of extreme effects such as tropical storms on local urban food production. This is of particular concern given that urban landscapes frequently exhibit more extreme weather impacts than rural areas due to increased impervious land cover.

A number of environmental changes have already come with urbanisation that affect the agronomic conditions necessary for food production (Pickett et al. 2001; Kaye et al. 2006) including changes in patterns of water availability, nutrient supply, soil degradation and pest pressure, affecting crop growth in urban areas (Eriksen-Hamel and Danso 2010). Extreme weather events add another layer of complexity affecting local production. However, urban agriculture systems may provide services that help regulate weather impacts. For example, many private and community gardens provide storm attenuation services to the urban landscape by decreasing the amount of impervious surface in cities. In German cities, allotment gardens used on green belts have been shown to facilitate drainage and reduce local flooding from storm events by allowing for a greater infiltration potential of precipitation (Drescher et al. 2006). In contrast, hard paving increases impervious surfaces, and in Leeds, United Kingdom (UK), increased hard paving in residential front gardens has been linked to more frequent and severe local flooding (Perry and Nawaz 2008).

Extreme Weather in Australia

Australia's major natural hazards are hydro-meteorological in nature. An Australian poet characterised Australia as a land "of droughts and flooding rains". The droughts make the countryside prone to wildfires known in Australia as bushfires—and the rains, as the poet emphasises, lead to floods. For the purpose of this paper, we will consider drought to be an extreme climatic event, rather than an extreme

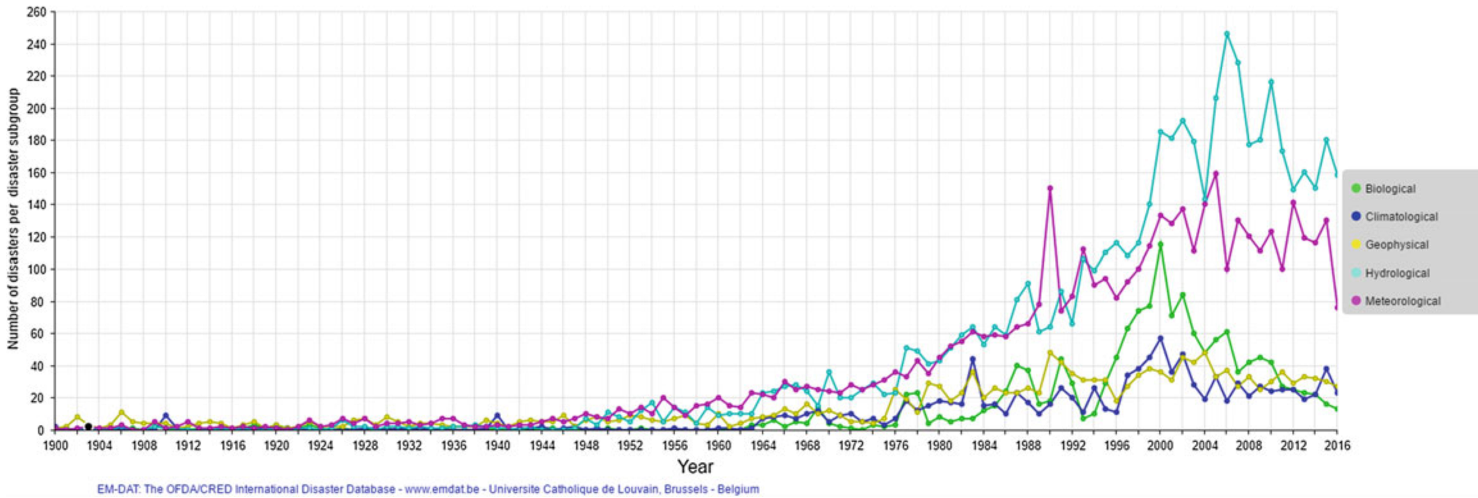

Fig. 2 Number of climatological, meteorological, hydrological, geological and biological disasters recorded in the EMDAT database of disaster trends. Source: D. Guha-Sapir, R. Below, Ph. Hoyois - EM-DAT: The CRED/OFDA International Disaster Database–www.emdat.be–Université Catholique de Louvain–Brussels–Belgium)

Table 1 Modified Saffir–Simpson tropical cyclone scale used by the Australian Bureau of Meteorology

Category	Wind description	Wind speed (km/h)	Typical effects
1	Gales	118–125	Minimal house damage. Damage to some crops, trees and caravans. Boats may drag moorings
2	Destructive winds	125–164	Minor house damage. Significant damage to signs, trees and caravans. Heavy damage to some crops. Risk of power failure. Small boats may break moorings
3	Very destructive winds	164–224	Some roof and structural damage. Some caravans destroyed. Power failure likely
4	Very destructive winds	225–279	Significant roofing and structural damage. Many caravans destroyed and blown away. Dangerous airborne debris. Widespread power failures
5	Extremely destructive winds	>280	Extremely dangerous with widespread destruction

weather event, and thus outside the scope of the discussion.

Rather than engage in a general discussion on flooding and its myriad causes, this chapter will consider only tropical cyclones and their consequences—one of which is flooding due to the extreme precipitation during a tropical cyclone. Other consequences of tropical cyclones are a decrease in atmospheric pressure that causes sea level rise in coastal locations and thus exacerbates coastal flooding. In addition, the extreme winds associated with a tropical cyclone can remove rooves and cause damage by slamming unanchored objects into people, houses and buildings. At coastal locations, the extreme winds will also drive large waves that batter the coast, erode shorelines and cause damage to buildings.

The Australian public is concerned both with the occurrence of tropical cyclones in the immediate future and seeks forecasts in the longer term about the distribution, landfall location and intensity of tropical cyclones. The rainfall in the Australian tropics is due to the effects of the monsoonal wet season, augmented by the extra rainfall from the occasional tropical cyclone. Though tropical cyclones themselves can produce strong winds, storm surges and floods, the combination of a particularly severe wet-season and a tropical cyclone can intensify the disaster and amplify the consequences.

Tropical Cyclones

On 25 December 1974, Tropical Cyclone Tracy[1] destroyed virtually all of the northern Australian city of Darwin causing the deaths of 71 people (49 on land and 22 at sea) and the evacuation of 75% of the city's residents. This event shocked the Australian public and encouraged the serious scientific study of Australian tropical cyclones.

This was not the first time that Darwin had been severely damaged by a tropical cyclone: In both January 1897 and March 1937 the city was badly damaged, but only after Tracy was more attention given to building codes and other social aspects of disaster planning. Darwin was rebuilt and is now a thriving city of 128,100 people as at June 2011.

The Bureau of Meteorology[2] provides a database of past tropical cyclones, histories of tropical cyclones and a library of individual cyclone reports. Australian Tropical Cyclones[3] are classified according to the modified Saffir–Simpson scale shown in Table 1, with Category 1 tropical cyclones having winds below 42 m/s but above 33 m/s, which is the minimum wind speed needed for a tropical storm to be classified

[1]http://www.bom.gov.au/cyclone/history/pdf/tracy.pdf.
[2]http://www.bom.gov.au/cyclone/history/index.shtml.
[3]http://www.bom.gov.au/cyclone/about/intensity.shtml.

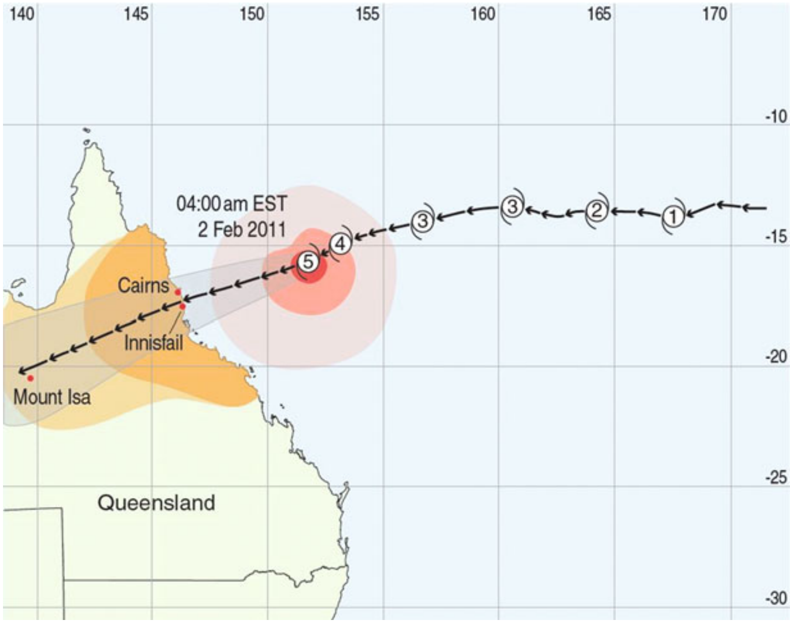

Fig. 3 Forecast track of TC Yasi as at 4am on 2 February 2011. Subsequent analysis downgraded the intensity from Category 5 at 4am to Category 4 though the same analysis indicates that TC Yasi became Category 5 at 4pm, just before landfall (Reproduced by permission of Bureau of Meteorology, © 2017 Commonwealth of Australia)

as a tropical cyclone. Category 5 tropical cyclones are the most intense and will cause catastrophic damage to structures.

There are, on average, approximately 12 tropical cyclones per year that are identified as occurring within the Australian region. Of these about 40% (~5) make landfall over the Australian continent. Tropical cyclones and tropical storms provide a large proportion of rainfall in tropical Australia that ranges from 40% in tropical Queensland to 60% in tropical Western Australia (Lavender and Abbs 2013). Tropical cyclone climatologies for Australia have been used to determine the tropical cyclone hazard.

Numerical weather prediction models have not, as yet, reached sufficiently fine resolution that they can predict the formation and subsequent strengthening and motion of a tropical cyclone. They are, however, able to identify tropical lows so that a sufficiently skilled forecaster is able to use such numerical weather prediction models, along with satellite photographs of tropical cyclone clouds that position the tropical cyclone, and thus use the two items of information to assist with forecasts of tropical cyclone tracks.

Once the tropical cyclone has made landfall, there are four particular impacts that need to be considered: strong winds; extreme rainfall; the flooding associated with the cumulative rainfall; and the short-term rise of sea level (known as storm surge).

During the severe wet-season of January–February 2011, the eastern coast of Australia was affected by three tropical cyclones: Severe Tropical Cyclone Zelia[4] from 14 to 18 January 2011, Tropical Cyclone Anthony[5] from 22 to 31 January 2011 and Severe Tropical Cyclone Yasi[6] from 30 January to 3 February 2011. Figure 3 depicts the track of Severe Tropical Cyclone Yasi. The scale shows very destructive winds in red, destructive winds in pink, and gale force winds are shaded.

[4] http://www.bom.gov.au/cyclone/history/zelia11.shtml.
[5] http://www.bom.gov.au/cyclone/history/anthony.shtml.
[6] http://www.bom.gov.au/cyclone/history/yasi.shtml.

Fig. 4 Motorists wait for water to subside over the Bruce Highway outside of Innisfail on 3 February 2011 in Innisfail, Australia following Cyclone Yasi which struck land as a Category 5 storm and destroyed the banana crop, as shown (AAP Image/Dave Hunt)

Extreme Weather and Food Availability

Production

Food production is the most visible, and the most studied, aspect of food security. Extreme events ruin crops. In the short term, hail can damage wheat; floods can ruin rice; strong winds can denude vegetation and destroy fruit crops as shown in Fig. 4. In the longer term, extreme events can be responsible for crop diseases, for silting of irrigation channels, destruction of rice terraces and injury to the personnel needed to work on food production.

Distribution

Figure 4 also depicts the logistical disruption consequent upon a severe weather event. The Bruce Highway, shown in the photograph, is the main highway linking communities in the northern part of Queensland. Even though the photograph depicts only passenger vehicles, cutting the highway in this manner meant that trucks were also not able to deliver food supplies.

Because food consumers outnumber producers in every country (Tweeten 1999), food must be distributed to different regions or nations. Food distribution involves the storage, processing, transport, packaging and marketing of food (FAO 1997). Food-chain infrastructure and storage technologies on farms can also affect the amount of food wasted in the distribution process. Poor transport infrastructure can increase the price of supplying water and fertiliser as well as the price of moving food to national and global markets (Godfray et al. 2010).

The distribution of food by aid agencies following a disaster can lead to inequities because of the impossibility of uniform food distribution. Certain areas—those near to airfields, for example—are likely to have preferential access to the incoming food supplies.

In practice, geography is only one of the many factors involved in such distribution and allocation. Nobel Prize-winning economist Amartya Sen has observed that “there is no such thing as an apolitical food problem”. While drought and other naturally occurring events may trigger famine conditions, it is government action or inaction that determines its severity, and often even whether or not a famine will occur.

Exchange

Around the world, few individuals or households are continuously self-reliant for food. This creates the need for a bartering, exchange or cash economy to acquire food (Gregory et al. 2005). The exchange of food requires efficient trading systems and market institutions, which can have an impact on food security (Ecker and Breisinger 2012). Per capita world food supplies are more than adequate to provide food security to all, and thus food accessibility is a greater barrier to achieving food security than is food production.

The discussion, above, on the history of Tropical Cyclone Yasi demonstrates the short to medium term disruption to food availability. In this case, the food production that was affected was only one crop—bananas. Though a blow to the local economy that led to a nationwide shortage of bananas, it did not lead to widespread hunger, famine or food shortages.

In this respect, we can contrast TC Yasi with TC Winston, also a Category 5 Tropical Cyclone that affected Fiji 20–21 February 2016 (Fig. 5). News reports from 24 February 2016 stated:

> Koro Island, which lies in the Koro Sea between Fiji's two largest islands, was one of the worst-hit by Cyclone Winston on the weekend. Aid is slowly arriving on the island but resident Serepe Pela, who lives in Nasau village, said more assistance was desperately needed.
> 'They need their houses to be constructed. At present all houses were ruined by Cyclone Winston,' he said. 'And foods, currently the food security level at Nasau is 5 per cent to 10 per cent. 'Maybe by next week there will be no more food.'
> Other residents on Koro Island told local media how several people were killed by huge waves whipped up by the cyclone.

Extreme Weather and Food Access

Affordability

It is probably a truism to state that after a disaster, if food is available, it will be expensive. In the case of TC Yasi (Fig. 2), a major portion of the Australian banana crop was wiped out causing extreme spikes in the banana price (Fig. 6)—repeating the situation of 2006 when Tropical Cyclone Larry made landfall on 20 March 2006 and also destroyed 80–90% of Australia's banana crop. Australia is relatively free of banana pests and diseases, imposes quarantine restrictions to ensure this continues and thus does not allow bananas to be imported. Bananas were in short supply throughout Australia for the remainder of both 2011 and 2006, which increased prices across the country by 400–500%.

In developing countries, aid agencies are aware of such increases in food prices and tend to distribute food to poor areas that are unable to afford to purchase food following a disaster.

Allocation

Food allocation may be seen as an example of food distribution, but the term "food allocation" has come to be used to describe the internal allocation of food within a household. A household's access to enough and nutritious food may not assure adequate food intake for all household members, as intra-household food allocation may not sufficiently meet the requirements of each member of the household. (Ecker and Breisinger 2012) The USDA adds that access to food must be available in socially acceptable ways, without, for example, resorting to emergency food supplies, scavenging, stealing or other coping strategies.

The application of military food distribution systems to disaster areas is a growing area of interest. The methods used by the military to feed armies in the field have obvious applications to emergency relief. Within the developed world, it is the military that has developed the logistical supply chains to feed troops in inaccessible areas and has made use of the advances in food science and technology to provide long-lasting, easy to transport, nutritious victuals. The organisation and deployment of such supplies is a political decision that is governed as much by the political relationship between a hardship area and a potential donor as it is by the urgency or the need of the recipient.

Preference

The most recognisable way to illustrate the importance of food preference is to consider the

Fig. 5 Location of Nakodu, the only village on Koro Island, emphasises the difficulty of providing food to an isolated rural community after a tropical cyclone. The red line that passes directly through Koro Island marks the approximate path of Tropical Cyclone Winston on 20 February 2016, (Image is reproduced with permission from the Pacific Disaster Center [PDC] http://www.pdc.org)

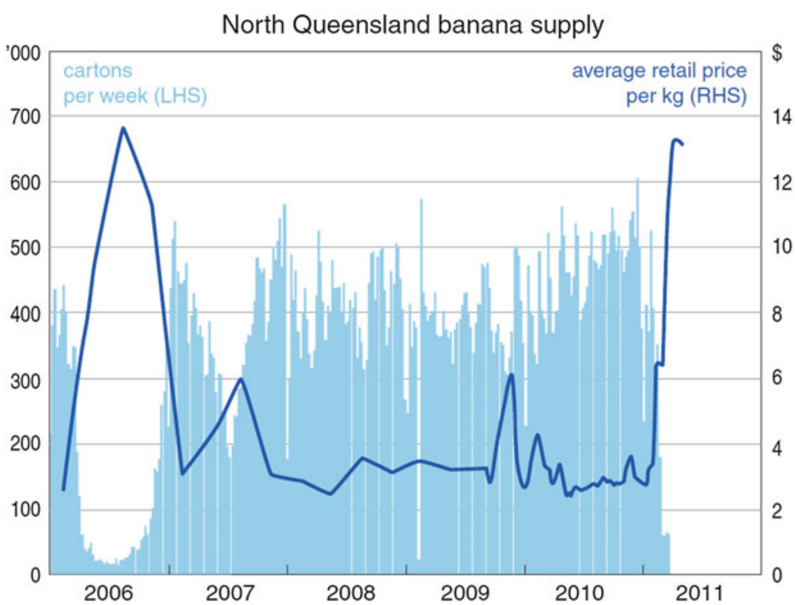

Fig. 6 Graph of the banana supply and banana price from the north-eastern part of Australia demonstrating the sharp price rises in banana price following Tropical Cyclones Larry (*left*) and Yasi (*right*) both of which destroyed most of the Australian banana crop. (Reproduced with permission of the Reserve Bank of Australia with acknowledgement to the Australian Bureau of Statistics, Australian Banana Growers' Council Inc. and the Reserve Bank of Australia for the provision of data)

food choices that follow from religious observance. Observant Muslims and observant Jews are prohibited from eating pork. This is so well known that no aid agency would think of delivering pork-based food to an Islamic disaster area, but many societies have less well-known dietary taboos either from religious or cultural practices. Delivering wheat products to areas that normally eat rice or delivering rice to areas that normally eat wheat products may not be as appreciated as the donor would like.

Extreme Weather and Food Utilisation

Nutritional Value

One of the key analytical pieces of information that a meteorologist should be able to calculate is the minimum nutritional requirement for a human being. Three key parameters in this calculation are:

The Stefan–Boltzmann constant = σ = 5.670367 $\times$ 10^{-8} W m^{-2} K^{-4}.
The skin temperature of a human being, which we take as T_s = 37 °C = 310 K.
The calorific value of food, for which we use the value of cellulose = 17 MJ/kg.
In the spirit of that wonderful book on environmental problem solving, "Consider a Spherical Cow" (Harte 1988), we shall assume a cylindrical human being that is 2 m tall and 0.25 m in radius. Using Stefan's Law, such a person emits 524 W m^{-2}.

Our idealised cylindrical person has a surface area of 3.5 m^2 and thus emits a power of 1852 W—approximately equivalent to the power of a strong bar heater—which means that there is something wrong with the calculations. If a typical person emitted 1852 W of radiation, then we would not need the electrical bar heaters used to heat rooms in winter.

More sophisticated calculations account for the fact that:

(a) the skin temperature is only 34 °C not 37 °C.
(b) long-wave radiation at the air temperature radiates into the skin offsetting the losses out.
(c) emissivity is only 0.97, as well as
(d) humans wear clothes, sweat and can thus use convection and diffusion as means to control heat loss.

The website at: http://hyperphysics.phy-astr.gsu.edu/hbase/thermo/bodrad.html presents a more sophisticated calculator in which, accounting for an ambient temperature of 23 °C the heat loss is 232 W = 232 J/s so that over a 24 h period a naked human being, totally at rest, needs to obtain 20 MJ of energy just to balance the heat loss through the skin.

As this is the largest source of energy loss we can, in rough terms, state that a human needs to eat about 1 kg of cellulose everyday. The FAO at: http://www.fao.org/docrep/007/y5686e/y5686e08.htm estimates that the basal metabolic rate lies between 6 and 8 MJ/day, indicating that by wearing clothes we need to eat about 700 g of food less than if we were naked and stayed out in the open. Nutritionists would express this in terms of calories, or kilocalories, rather than in Joules and can provide tables of the calorific value of different foods.

There are two questions in relation to nutritional value. Is sufficient food being eaten? Is it the right kind of food? Famine stricken peasants do not get sufficient food. Obese westerners do not get the right kind. Both situations are problematic.

Social Value

To some extent, the social value of food mirrors the food choices discussed under "preference"; except that in the case of social value, it is cultural norms rather than religious strictures that determine the preferable, acceptable or non-acceptable foods and the ways in which they can be distributed, cooked or eaten within the family and within the community.

A graphic example of the difficulties that arise when donors with different social values attempt to assist starving communities is given in the description of the Irish Potato famine in "The Great Hunger" by Woodham-Smith (1992), where it is pointed out that the well-intentioned attempts by the English to teach Irish peasants to cook cheap foods foundered because the peasants had neither pots, nor pans nor kitchens nor fuel.

Food Safety

Under normal circumstances, developed nations have food inspection and certification systems in place to guarantee the quality and safety of the foods that are sold. In developed countries where food purchases may take place in the bazaar or market, rather than the supermarket, the assurance of food safety is tied to the reputation of the trader that sells the food.

The disruption of the logistical supply chain following a major disaster makes it more difficult to guarantee the safety of the food and infection of common organisms such as Salmonella or *E. Coli* may occur because the food that is being eaten is old, has been improperly stored or has been contaminated. In extreme disasters, the corpses of the people that have been killed may contaminate the drinking water and contamination may be transmitted by those handling these bodies.

Discussion

International Co-operation

The International Union of Geodesy and Geophysics (IUGG) led a consortium of international scientific unions to examine weather, climate and food security (WeatCliFS[7]) as well as to look at the interaction of food security and geophysical phenomena. A question that underpinned their effort was: *What technologies and methodologies are required to assess the vulnerability of people and places to extreme events that lead to famine.*

As a general rule in relation to disasters, a major difference between the response in developing countries and developed countries is that in developing countries fatalities dominate. In developed countries, infrastructure and property losses dominate. In relation to food issues, a major disaster in a developing country, such as a large-scale drought, wildfire or extensive flood, has the potential to lead to famine whereas an analogous disaster in a developed country will lead to price increases (Fig. 6).

Future Earth

Future Earth, previously known as the Earth Systems Science Partnership, is a major initiative of the International Council of Science (ICSU) formed by bringing together the existing work of three interdisciplinary programmes—the International Geosphere Biosphere Programme (IGBP); the International Human Dimensions Programme (IHDP); Diversitas, an international biological programme. The World Climate Research Programme (WCRP) has also agreed to partner with Future Earth.

It was recognised that food security would be an important part of Future Earth[8] (Fig. 1), and thus Future Earth and the Consultative Group on International Agricultural Research (CGIAR) agreed that the CGIAR research programme on Climate Change, Agriculture and Food Security (CCAFS) would become one of the initial research programmes of Future Earth. Thus, it may be stated that at an international level the Weather and Food Security link, or at least the Climate and Food Security link, has been made in terms of Climate Change—Agriculture—Food Security through the work of CCAFS. Less international effort has been devoted to examining the Weather—Fisheries—Food Security link or the Weather—Supply Chain—Food Security link, which is a particular concern of the International Union of Food Science and Technology (IUFoST).

[7] The acronym stands for Weather, Climate and food security. See http://ccec-iugg.org/sites/default/files/files/CCEC%20report2013(1).pdf.

[8] http://www.planetunderpressure2012.net/policybriefs.asp.

There is also ongoing work on weather and food security, especially the role of seasonal forecasting in improving agricultural yields (Iizumi et al. 2013) which showed that improved forecasts can be achieved worldwide if the state of ENSO, the El Nino–Southern Oscillation, is incorporated into yield forecasts. However, work by Asseng et al. (2013) indicates that a greater proportion of the uncertainty in projections of crop yields is due to variations among crop models rather than to variations among the downscaled weather or climate models.

Conclusions

Despite the existence of the ICSU research programme Integrated Research on Disaster Risk, the science plan for IRDR (ICSU 2008) indicates that food security is not an aspect of its research mandate. Thus, the international aspects, including the urban aspects, of the agricultural disruption, economic disruption and logistical disruption to food availability, food access and food quality as a result of natural disasters remain an under-researched topic.

Climate change is affecting (and will affect) global food production and hence global food security both through changing climate and through the occurrence, possibly increased occurrence, of extreme weather events resulting from climate change. Urban agriculture plays a significant role in maintaining and improving the health of city dwellers, particularly those disadvantaged. Extreme weather effects are likely to impact more severely on urban environments with associated negative effects on food security, as has been discussed. Existing research programmes are not addressing these aspects of extreme weather effectively and deserve immediate attention.

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Sedimentation-Induced Depositional Lands of the Gumti River of Tripura and Its Land Use Pattern

Istak Ahmed and Nibedita Das (Pan)

Abstract

Sedimentation is the process through which sediment carried by the running water is deposited in suitable places. When the energy of a river to carry load gradually decreases, sediment gets deposited and gives rise to bar formation. Due to gradual siltation, area of bars gradually increases and it eventually turns into stable land which uses to be very fertile. With the passage of time, various human activities started to develop on this fertile land and give rise to diverse land use patterns. Gumti is the largest and longest river of Tripura. Lower course of the river is highly prone to sedimentation. Lots of bar formation can be identified in this part of the river, the area of which gradually increases and gives rise to new depositional land. Thus, the objective of the study is to identify the change in channel plan form (sinuosity index and radius of curvature) during the period 1932 to 2016, to measure the area of depositional land generated during this period and to analyse the present land use pattern of this land. For this purpose, the study area has been categorized into several reaches and the layers of different years have been superimposed. Finally, the land use map of the area has been prepared using Global Mapper Software. The results indicate that the River Gumti is gradually changing its channel pattern from meandering to sinuous by increasing meander wavelength due to combined effect of erosion and sedimentation. Besides, with the passage of time diverse land use pattern has been developed in the sedimentation-induced depositional land, the forms of which eventually change due to increasing human habitation.

Keywords

Gumti River · Sedimentation · Depositional land · Land use pattern

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Introduction

Sedimentation is a dynamic and continuous process of river. It operates through the chain of erosion of geo-materials, transportation of these eroded materials called as sediments and deposition of these materials (sediment) in different parts of river (Singh 1998). Aggradations of a specific river reach occur when the sediment entering the reach is larger than the carrying capacity of the river water (Torres and Jain 1984). The evolutions of floodplains are largely depending on the sedimentation process. Several studies have been conducted in the past to understand the pattern, amount and characteristics of floodplain sedimentation (e.g. Marriott 1992; Guccione 1993; He and Walling 1997, 1998; Simm and Walling 1998; Lecce and Pavlowsky 2004). Moreover, gradual sediment deposition leads to spatial and temporal variation in the extension of bar. A shoal becomes a bar and gradually increases in length, width and height due to decrease in discharge and increase in sediment load (Das 2012). As a result changes in morphological characteristics of river like sinuosity index (SI), radius of curvature, etc., took place. Besides, combine effect of erosion and deposition leads to frequent shifting of channel. Apart from this, gradual sedimentation eventually gives rise to new depositional land within the river channel. In due course of time, increased inhabitants within these depositional lands give rise to diverse land use pattern. The Gumti is the largest river of Tripura, the lower course of which is very much prone to siltation problem. The present study aims to identify the changes in channel characteristics of the Gumti River during the period 1932–2016 (84 years) and to measure the areas under deposition in different reaches. Besides, changes in areal extension under bar from 2009 to 2016 in different reaches of the river have also been measured to identify the impact of sedimentation.

Study Area

The study area is extended between 23°30′22″ N and 23°32′45″ N latitude and 91°24′42″ E–91° 29′08″ E longitude, i.e. a 15-km-long stretch of the Gumti River from Udaipur (Reach 1) to Palatana (Reach 5) located in the lower course of the river (Fig. 1). The area is characterized by floodplain, piedmont slopes and uplands where younger and older alluvial soils predominate.

Materials and Methods

To carry out the present study, Geomatica V 10.1, Global Mapper 11 (for GIS mapping), SOI topographical maps, Landsat and Google Earth imagery have been used. In order to identify the position of the Gumti River in 1932, Survey of India topographical sheet (79 M/6, 79 M/7) has been geo-referred and mosaicked. Then, layer of the river channel has been created by digitization and extracted using Geomatica software. Landsat MSS imagery has been used to generate layer of river channel of 1978. Both the layers have been exported to Google Earth Imagery to superimpose it on the present river course (2016) of the Gumti River.

A 15-km stretch of the Gumti River from Udaipur to Palatana has been selected for the present study as it is very much prone to sedimentation. The course of the base year (1932) then divided into five reaches, each of 3 km length (Table 1). Layers of depositional lands generated for 1932 and 2016 and different land use classes developed over those lands have been generated from Google Earth Imagery (2016). The layers then opened up in Global Mapper 11 Software to measure the area under deposition and area under different land use classes to prepare different maps. Apex of the meander bends is selected for cross sections to measure radius of curvature for the year 1932 and 2016 (Fig. 3).

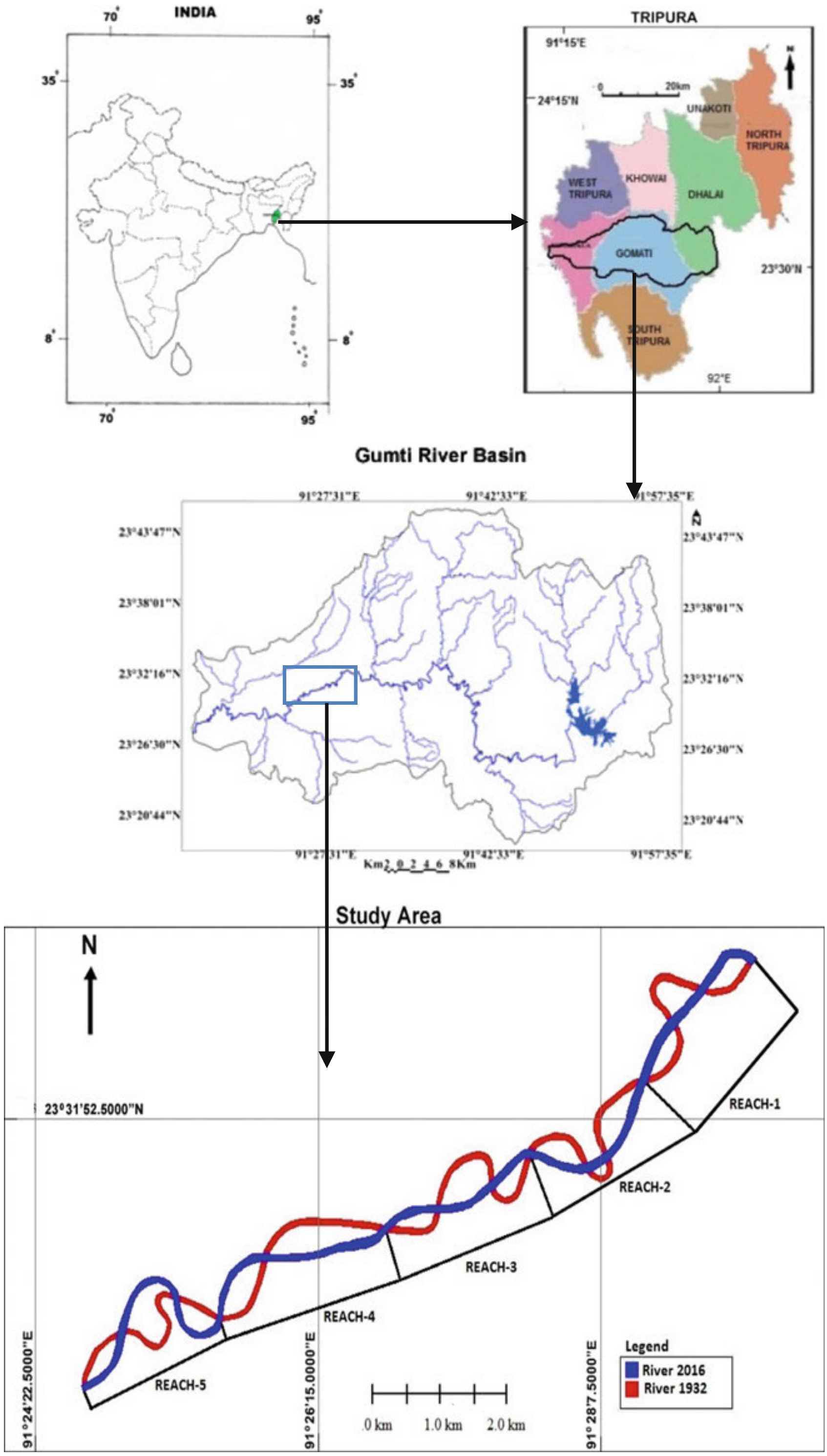


Fig. 1 Location of the study area (river flow towards west direction)

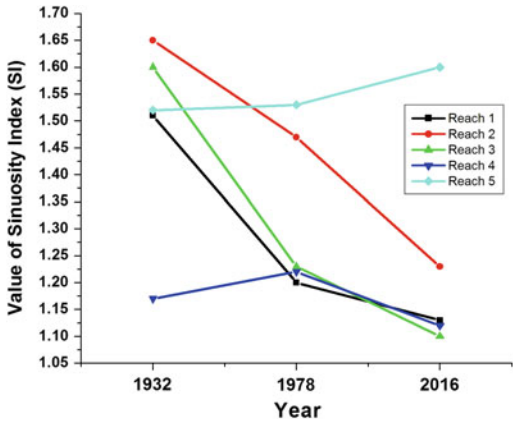
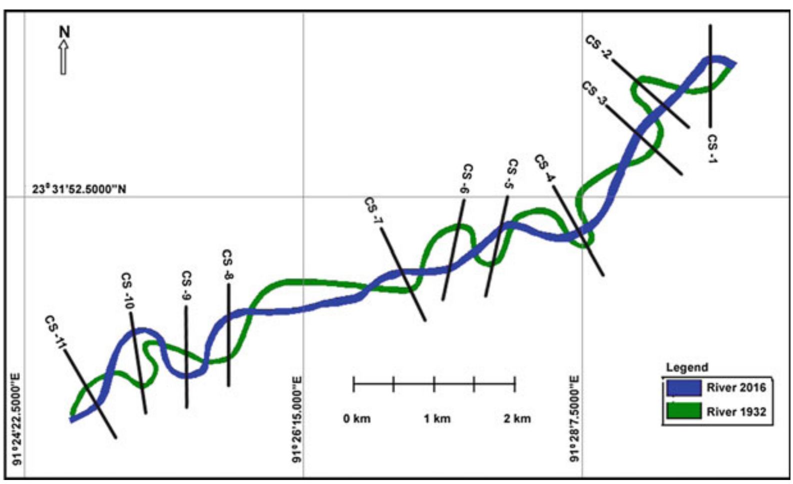


Fig. 2 Variation of sinuosity index in five reaches of the Gumti River from 1932 to 2016

Table 1 Extension and characteristics of five reaches of the Gumti River

Reaches	Extension		Discharge (cumec)	Velocity (m/sec)	Bed sediments type
	Longitude	Latitude			
Reach 1	91°29′08.05″–91°28′24.10″ E	23°32′45.77″–23°32′05.63″ N	10.22	.27	Medium sand
Reach 2	91°28′24.10″–91°27′39.39″ E	23°32′05.63″–23°31′40.86″ N	9.54	.34	Fine sand
Reach 3	91°27′39.39″–91°26′43.78″ E	23°31′40.86″–23°31′17.45″ N	10.93	.33	Fine sand
Reach 4	91°26′43.78″–91°25′36.55″ E	23°31′17.45″–23°30′45.25″ N	10.78	.35	Fine sand
Reach 5	91°25′36.55–91°24′42.71″ E	23°30′45.25″–23°30′22.57″ N	9.59	.37	Fine sand

Fig. 3 Location of different cross sections across the meander bends



Each cross section is numbered from upstream towards downstream. The formula suggested by Schumm (1963) has been followed to measure sinuosity index of these two years.

$$\text{Channel sinuosity} = \frac{OL}{EL}$$

where OL = observed path of a stream and EL = expected straight path of a stream.

According to this formula, channels can be divided into three classes: straight (SI < 1.05), sinuous (SI = 1.05–1.5) and meandering (SI > 1.5).

Results and Discussion

Sinuosity Index

Sinuosity of a stream denotes the degree of deviation of its actual path from expected theoretical straight path. Value of sinuosity index indicates the pattern of channel in a given reach. The complete range of river patterns from straight through meandering to braided is dependent on stream power which is, in turn, controlled by velocity, discharge and sediment load. The study of sinuosity of the Gumti River indicates that value of sinuosity index has decreased from 1932 to 2016 in all the reaches except in Reach 5 (Fig. 2) due to combined action of erosion and sedimentation. It reveals that from Reaches 1 to 4, the River Gumti shows a tendency to transform its course from meandering to sinuous pattern by shortening its course. Only in Reach 5, the value of sinuosity has increased from 1.51 in 1932 to 1.6 in 2016 which indicates that the river is gradually expanding its meander bend through erosion in this reach.

Radius of Curvature

Radius of curvature is the radius of the circle drawn through the apex of meander bend. The loops of a meandering stream are more nearly circular, and the radius of the loop is considered to be the straight line perpendicular to the down-valley axis intersecting the sinuous axis at the apex (Deb et al. 2012) (Fig. 3).

Hickin (1974) considered that the process of meander development and migration is largely dependent on the radius of curvature. Besides, the process of cut-off formation is also controlled by radius of meander bend. Study of radius of curvature along the meander bend reveals that in maximum cross sections (64%) meander bends show an increase in radius of curvature (Table 2). It indicates that the river is gradually increasing its meander wavelength by means of change in channel pattern from meander to sinuous which has been discussed above. While in cross section 2 and 9, the river had totally abolished its meander bend by leaving it as cut-off

Table 2 Variation in radius of curvature across different cross sections from 1932 to 2016

Cross sections	Radius of curvature (m)	
	1932	2016
Cs-1	280	254
Cs-2	193	0
Cs-3	316	263
Cs-4	160	655
Cs-5	175	263
Cs-6	351	586
Cs-7	285	350
Cs-8	403	473
Cs-9	263	0
Cs-10	193	270
Cs-11	403	438

and gradually transformed into depositional land. Therefore, variation in meandering geometry of the Gumti River has been observed during the study period 1932–2016. One of the major reasons behind it is sedimentation problem as river always has the tendency to deposit its sediment in the inner bend of meander in the form of point bar which initiates shifting problem.

Changes in the Area of Channel Bar Due to Sedimentation

The channel bar formation is a process of interrelationship between flow and sediment in terms of bed load and suspended load (Mat Salleh and Ariffin 2013). Bars are the imprint of sedimentation problem. One of the major reasons for change in channel plan form of the Gumti River like sinuosity index, radius of curvature, etc., is due to gradual sedimentation in the river channel. Result of the analysis on variation in the areal extent of channel bars of the Gumti River from 2011 to 2016 reveals that in all the five reaches area under bar has been increased at an alarming rate. The highest area under bar formation in 2016 has been observed in Reaches 1 and 2 which is 8.74 acre and 9.1 acre, respectively (Figs. 4 and 5). But the rate of increase from 2011 to 2016 is relatively higher in Reaches 4 and 5 in comparison with the first two reaches, which is 1.3 acre/year and 1.15 acre/year, respectively. It indicates that these two reaches are highly prone to sedimentation over the last few years. While in several areas like at Radhakishorepur (Udaipur-Reach 1), mid-channel bar has frequently been converted into stable bar due to gradual sediment deposition (Plate 1).

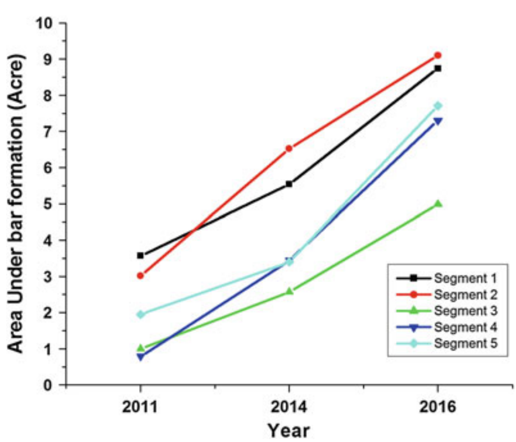


Fig. 4 Increased area under bar formation in five reaches of the Gumti River

Sedimentation-Induced Depositional Land

River morphology is largely associated with mainly two types of activities, erosion and deposition, among which the more stationary is the deposition (Ghosh and Saha 2014). Deposition of river sediment is largely governed by the interrelationship between velocity, discharge and sediment load. Decrease in stream velocity reduces the transporting power of streams which are forced to leave additional load to settle down and initiate sedimentation process. Gradual sedimentation leads to the formation of new depositional land which in turn results in the migration of channel. Analysis regarding variation in the area under depositional land in five reaches of the Gumti River during the period 1932–78–2016 has been carried out. It has been observed that in all the reaches, except Reach 3, area under deposition has increased during the later period (1978–2016) than the earlier period (1932–1978) (Fig. 7). Maximum depositional area generated during this period is in Reach 2 which is 94 acres. The rate of deposition in five reaches during 1932–1978 period ranges between 0.76 and 1.60 acre/year which has increased to 1.17–2.47 acre/year during 1978–2016 periods. It indicates that during the last three decades the rate of sedimentation has increased in the River Gumti. It has emerged to be a burning issue as it hampers the navigability of the river.

Reach-Wise Variation in Land Use Pattern on Depositional Land

Sedimentation is one of most important factors controlling floodplain formation. Floodplains have been extensively used for human activities

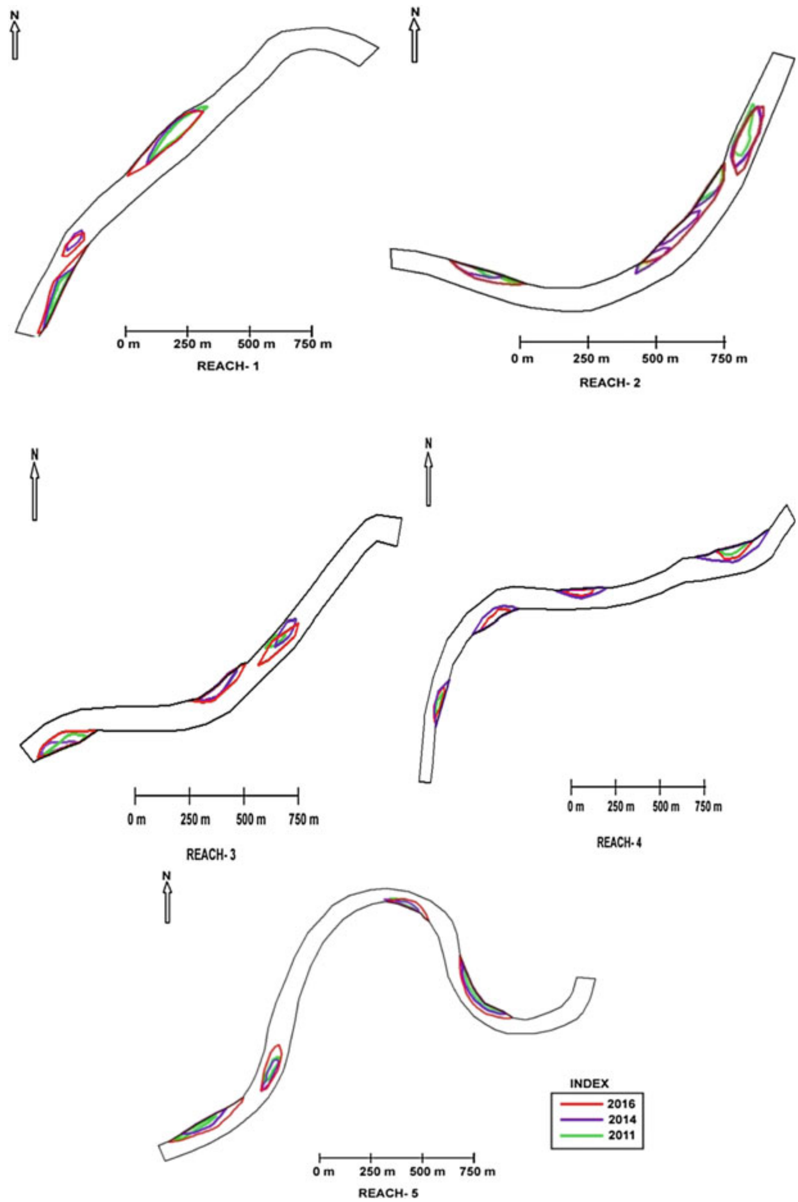


Fig. 5 Variation in areal extent of bars due to sedimentation in different reaches from 2011 to 2016

like agriculture, settlement and industry for millennia and are vulnerable to morphologic changes to adjacent channels (Ghoshal et al. 2010). In the present study, reach-wise variation in land use pattern developed on the depositional land generated within the Gumti River channel in 1932 and 2016 has been analysed (Fig. 6). It has been observed that all the reaches are dominated by agricultural land use. Maximum area under agriculture is found in Reach 3 which is 86 acre (Fig. 8). The result of survey reveals that most of the agricultural lands are double cropped in nature which is largely dependent on the water of the Gumti River. Besides, area under natural vegetation is mostly predominant in Reach 4 (27.22 acre) and Reach 5 (30 acre) a significant

Plate 1 Increased areal extent of bar at Radhakishorepur due to sedimentation (2009–2016)

portion of which falls under plantation. Among all the reaches, most area occupied by settlement is in Reach 1 (21.18 acre) because part of the Udaipur town falls in this reach. Settlements are dispersed in nature in all the reaches except in Reach 1. Area under water body is mostly found in Reach 3 (1.26 acre) which is mostly used for pisciculture to meet the local demands. Besides, it has been observed that Reach 2 has most area under sand bars in comparison with other reaches (Fig. 8) which indicate its proneness to sedimentation. (Fig. 7)

Thus, the study reveals that diverse land use pattern has been developed on the sedimentation-induced depositional land of the Gumti River over time. But increased population pressure along the bank of the river has diverse

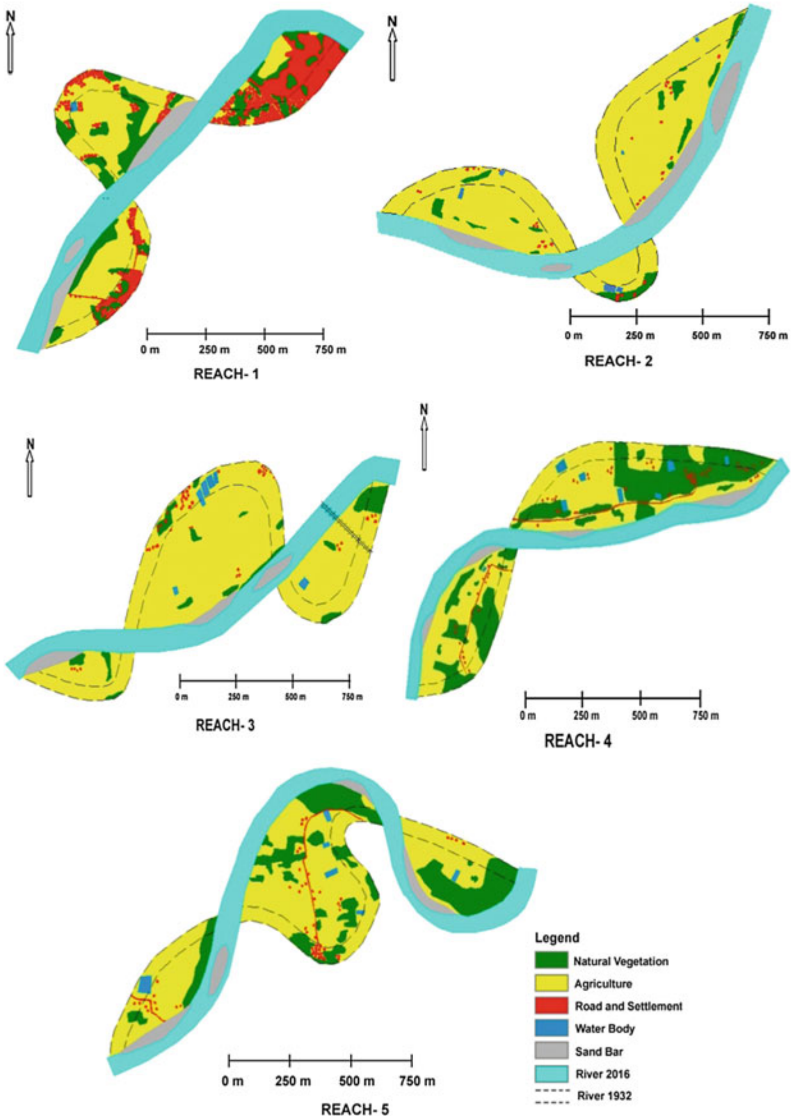


Fig. 6 Reach-wise variation in land use pattern develops on the depositional land generated during 1932–2016

negative impact. Unscientific agricultural practice, especially along the bank, is one of the key sources of increased sediment supply to the river (Plate 2). Moreover, increased urbanization along the bank of the river has resulted in the deterioration of water quality of the river.

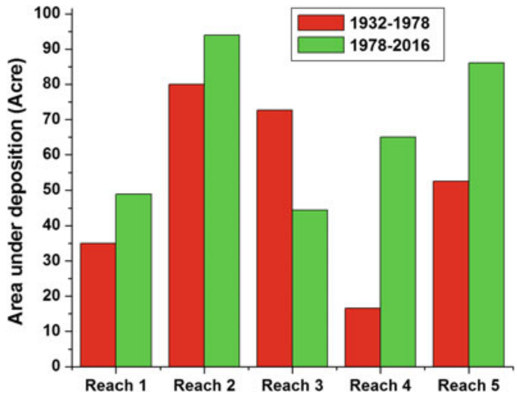


Fig. 7 Depositional land generated in five reaches of the Gumti River during 1932–1978 and 1978–2016

Fig. 8 Variation of area under different land use classes develops on the depositional land generated during 1932–2016

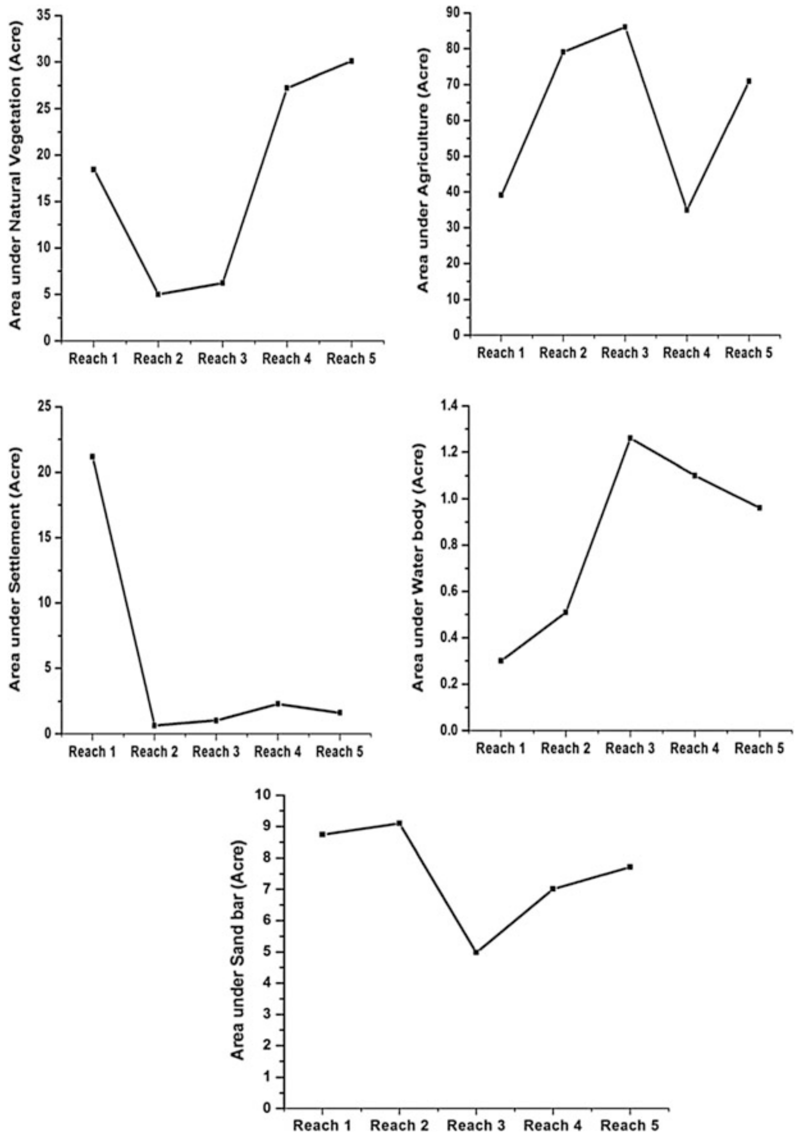


Plate 2 Unscientific agricultural practice along the bank of the Gumti River which results in increased sediment supply to the river

Conclusion

The present study reveals that the rate of sedimentation in the Gumti River channel has increased during the period 1978–2016 than the period 1932–1978. The combined effect of erosion and sedimentation leads to the frequent changes in channel plan form like sinuosity index, radius of curvature. Thus, the river is gradually shifting its channel from meandering towards sinuous pattern. Besides, gradual siltation and frequent bar formation pose threat to the navigability of the Gumti River. Although diverse land use pattern is developing on the sedimentation-induced depositional land but at the same time, increased urbanisation along the bank of the river and unscientific agricultural practices result in the increased sediment supply to the river and deteriorate its water quality.

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Changes in the Activity of Higher Vascular Plants Species in the Ob Plateau Landscapes (Altai Krai, Russia) Due to Anthropogenic Transformation

D.V. Zolotov, D.V. Chernykh, R. Yu. Biryukov and D.K. Pershin

Abstract

The paper deals with the attempt to assess the changes in plant species activity as a result of anthropogenic transformation of landscapes. The approaches of the Russian–Soviet school of landscape cartography and land cover mapping based on remote sensing data are used. The species activity was determined by standard methods accepted in the Russian–Soviet floristics. Using the specific examples, the main trends of the species activity changes from the natural condition of the territory to the present moment and in the last 40 years are shown.

Keywords

Plant species activity · Landscape mapping · Remote sensing data Land cover classes

Introduction

The Altai Krai flora is currently detected with high completeness, and the native and alien species in its structure are recognized (Silantyeva 2013). However, the attempts to reconstruct the process of flora anthropogenic transformation only at a general qualitative level were made. In other words, it is known which species belong to native flora and what species and about what time have been entered due to human activities. Nevertheless, the quantitative assessment of changes in the activity (Yurtsev 1968) of native and alien species under the action of anthropogenic pressure in the Altai Krai is still not performed.

Of course, the most accurate and correct way to study changes in the activity of specific species in the landscape is the direct floristic surveys in different time slices. It should be noted such surveys require much time and many researchers, so they cannot be carried out simultaneously over

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large areas such as the Altai Krai, or even the Ob plateau. In addition, often the lack of similar data for the past time slices excludes the possibility of comparison. In this case, it is necessary to use indirect methods for determining the species activity that is especially important for the past time slices.

Flora is a component of the landscape and transformed together with other components and the landscape as a whole. We asked ourselves how we could assess the anthropogenic transformation of the flora as a result and part of anthropogenic transformation of landscapes.

This is possible using the identification of linkages between the partial components of the landscape, as well as between the components and physiognomic characteristics of the landscape (e.g., land cover). Specific species are associated with specific ecotopes, so the species distribution in the landscape can be assessed through the distribution of ecotopes. Accordingly, changes in the distribution of species can be estimated due to changes in areas and distribution of relevant ecotypes. The study of changes in the area and distribution of ecotopes is only possible with the use of cartography and a series of maps for two or more time slices. In this work, we attempted to link changes in the structure of landscape and flora.

Methodology and Study Area

In 1995–2016, we carried out floristic (Zolotov 2009) and landscape (Chernykh and Zolotov 2011) research on the Ob plateau within the key model territories (Fig. 1). The result is a data array that allows to compare floristic and

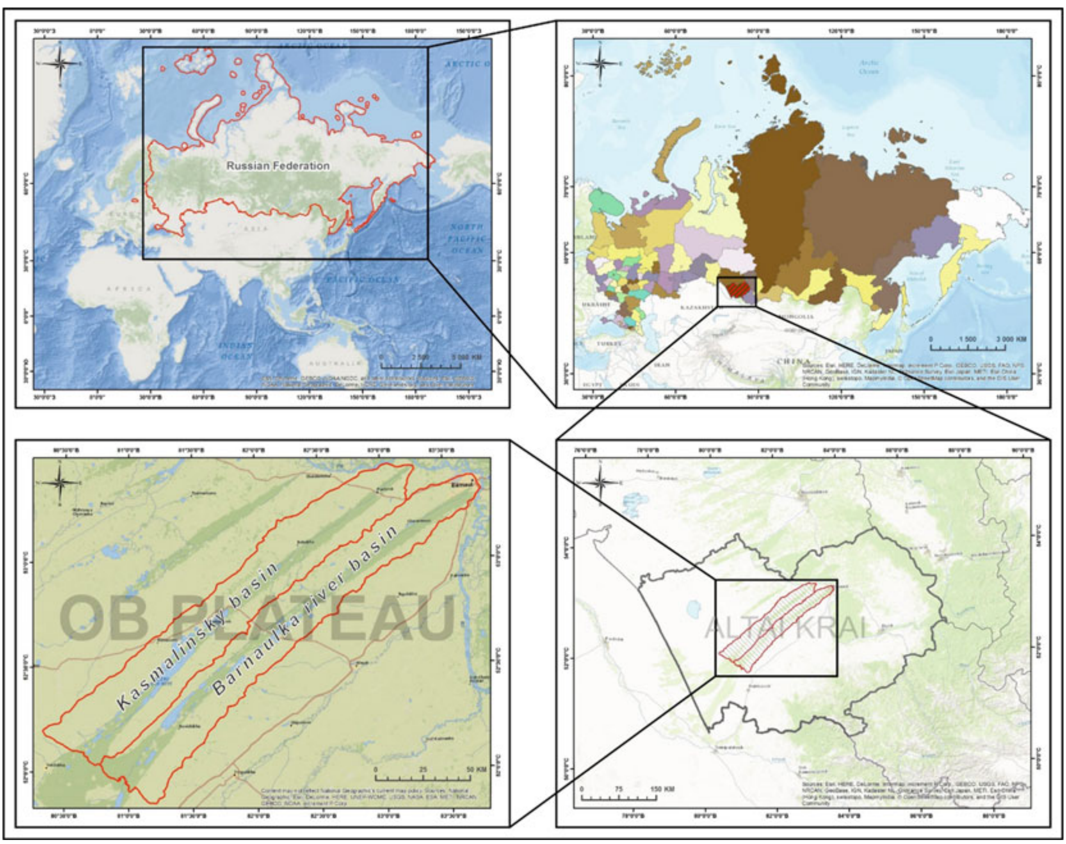


Fig. 1 Study area: the Kasmalinsky and Barnaulka river basin at the Ob plateau

landscape diversity, to explore their interrelation, and to assess the anthropogenic transformation of the flora due to anthropogenic transformation of landscapes. To our opinion, such a goal requires to solve three particular tasks:

(1) Creating a map of the restored landscapes based on the reconstruction according to the available historical (archival) data and documents. The detection of anthropogenic landscape dynamics for the considered periods including the remote sensing data using.
(2) The complete inventory of the modern flora and its analysis, gathering historical data on the occurrence and abundance of species in the past. The division of species into anthropophobic, hemianthropophobic, hemianthropophilous, and anthropophilous ones.
(3) The determination of the nature of relationship between species and ecotopes (eurytopic, hemieurytopic, hemistenotopic, and stenotopic species) for extrapolation and interpolation of data on different periods.
(4) To assess the landscape situation before the major economic development of the beginning of eighteenth century, the map of restored landscapes of the Kasmalinsky and Barnaulka river basins (Fig. 3) is composed. The map is made in the tradition of Soviet–Russian school of landscape science at the level of types of terrain groups (output scale of 1:500,000, working scale of 1:200,000). Previously, we produced a similar map for the Barnaulka river basin (output scale of 1:250,000, working scale of 1:100,000) (Chernykh and Zolotov 2011). Landscape dynamics for the last 40 years is studied using remote sensing data.
(5) To identify the role of higher vascular plant species in the landscape, we used the activity (Yurtsev 1968; Yurtsev and Petrovsky 1994; Zverev 2007)—integral index of occurrence and abundance.

It is obvious that the reconstruction cannot give absolutely accurate data. Therefore, for many rare non-stenotopic species, it is extremely difficult to reliably estimate their activity in the past, especially because they are not mentioned in previous floristic checklists. However, for many widespread, dominant, stenotopic, and flagship species, it is possible to evaluate the activity knowing the landscape situation in the past with sufficiently high precision. This is possible because of ecological and coenotic characteristics of higher vascular plant species in the last hundreds and thousands of years remained practically unchanged.

In general, this study is our first step in the direction of set goal and tasks. Nevertheless, the used approach allowed us to draw some interesting conclusions.

Results and Discussion

Highest hierarchical levels of the Ob plateau landscape differentiation are regional and subregional. The regional level is manifestation of zonal or bioclimatic differentiation: steppe and forest-steppe zones (landscape types), droughty and temperate-droughty steppe, southern forest-steppe subzones (landscape subtypes) (Fig. 2). The subregional level is the three basic landscape genera of the Ob plateau: *zonal* watershed-loessial (loessial ouval plateau), *intrazonal* halohydromorphic (ancient-alluvial flat with flat-bottom depressions), *extrazonal* psammomorphic (eolian-ancient-alluvial bumpy with flat-bottom depressions) (Chernykh and Zolotov 2011).

Anthropogenic transformation of the Ob plateau territory as a result of economic development was determined by the spatial organization of landscapes. Anthropogenic transformation degree increases in the landscape genera row: *extrazonal* psammomorphic → *intrazonal* halohydromorphic → *zonal* watershed-loessial (Fig. 3).

Weakly transformed are extrazonal psammomorphic landscapes (4371 km^2—35%), within which the forestry (felling in strip pineries) and residential activities were primarily evolved. This category also includes the valleys of small rivers and temporary watercourses within the zonal and intrazonal landscapes.

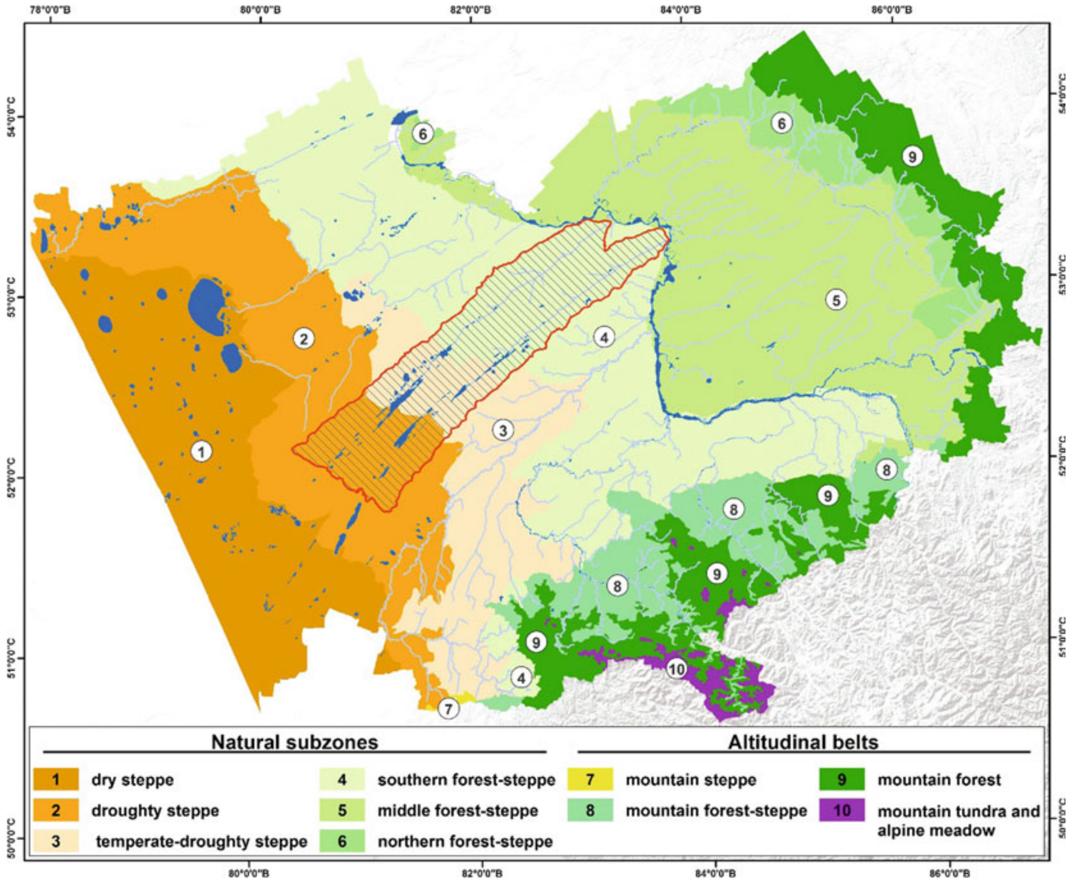


Fig. 2 Natural subzones and altitudinal belts of Altai Krai

Medium transformed are intrazonal halohydromorphic landscapes (1972 km^2—16%). Within their limits, the arable land is limited by light granulometric composition (loamy sand, light loam, and sand) and paleohydromorphism (plenty of flat-bottom depressions and saline areas unsuitable for growing). However, there are concentrated majority of settlements and main pastures.

Much transformed are zonal watershed-loessial landscapes (6155 km^2—49%), which are optimal for agriculture, first of all plowing. Here, all suitable areas are under cultivation, and pastures are confined to the balkas (small flat-bottom valleys), small river valleys, suffusion depressions, and residual lake basins. Settlements are usually small, relatively rare, and gradually disappear from the 1960s.

Some reduction of anthropogenic transformation is observed in landscape subtypes row: droughty steppe → temperate-droughty steppe → southern forest-steppe. This is due to the increase of precipitation, intensification of erosion processes, and consequently area unfit for cultivation. Most clearly, this zonal trend is apparent in the zonal watershed-loessial landscapes. Less clearly, it is observed in intrazonal halohydromorphic landscapes, especially because their area is reduced in the described direction also under the influence of erosion processes. The manifestation of this regularity is almost imperceptible in extrazonal psammomorphic landscapes that are not affected by plowing.

It is well known that the higher vascular plant species change their activity in landscapes as a result of anthropogenic transformation. In this

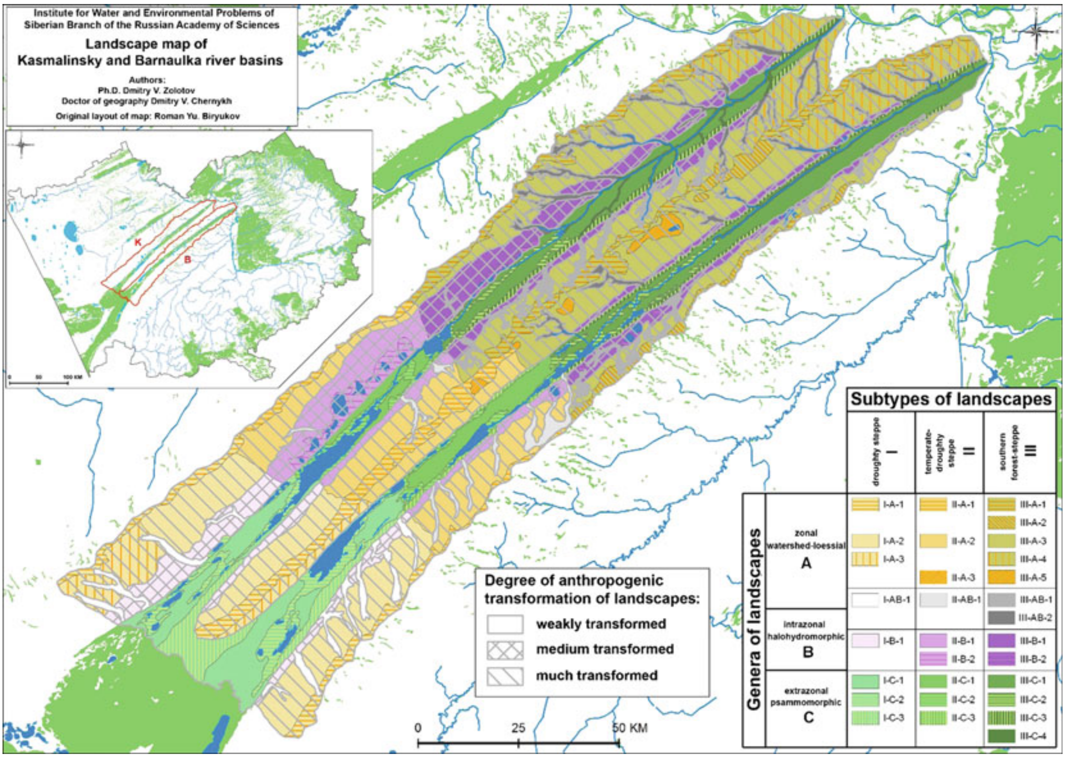


Fig. 3 Landscape map of the Kasmalinsky (K) and Barnaulka (B) river basins with degree of anthropogenic transformation at level of types of terrain groups

case, anthropophobic species reduce their activity, but anthropophilous ones (apophytes and aliens) increase. We used the activity (A) gradation proposed by B.A. Yurtsev (Yurtsev 1968; Yurtsev and Petrovsky 1994; Zverev 2007) for species in landscape: 1—inactive (IA), 2—low-active (I), 3—low-mid-active (intermediate I–II), 4—mid-active (II), 5—high-mid-active (intermediate I–III), 6—high-active (III), 7—particularly active (IIIA).

Theoretically, the amplitude of changes of the species activity due to anthropogenic transformation of landscapes can be from 0 to ±7. We offer the following gradation to estimate activity changes (ΔA): 0—no changes, 1—slight (visible), 2—significant (strong), 3 to 4—very significant (very strong), 5 to 7—extreme (catastrophic).

As a result of anthropogenic transformation of the Ob plateau landscapes from the initial natural state to a modern one, the activity of steppe species, especially dominants (*Stipa zalesskii* Wilensky, *S. pennata* L., *S. capillata* L., *Festuca valesiaca* Gaudin), is very significantly and extremely decreased in zonal and intrazonal landscapes.

The activity of halophytes [*Atriplex verrucifera* M.Bieb., *Camphorosma songorica* Bunge, *Salicornia perennans* Willd., *Suaeda corniculata* (C.A.Mey.) Bunge] in intrazonal landscapes is almost not decreased and in some location increased due to secondary salinization.

Minor changes associated with felling have affected the species of mesophytic strip pineries in extrazonal landscapes. First of all, there are trees: *Pinus sylvestris* L., *Betula pendula* Roth, *Populus tremula* L.

On the contrary, the species of forest swamps (*Oxycoccus palustris* Pers., *Drosera anglica* Huds., *D. rotundifolia* L., and other) and moist forests have visibly reduced their activity due to anthropogenic disturbances of hydrological regime and climate warming. The activity of many alien species (*Acer negundo* L., *Cannabis sativa* L., *Erigeron canadensis* L., *Hordeum jubatum* L., *Pastinaca sylvestris* Mill., *Trifolium fragiferum* L., *Xanthium strumarium* L.) has increased significantly, very significantly, and extremely.

We have estimated the anthropogenic and natural dynamics of landscapes of the Kasmalinsky and Barnaulka river basins in the last 40 years using remote sensing data and geoinformational methods (Fig. 4). Multi-temporal series of satellite imagery were used: 1975–1976 Landsat 2 MSS; 2001 Landsat 7 ETM; 2015 Landsat 8 OLI (http://glovis.usgs.gov). The analysis of spatiotemporal changes of landscapes has fundamental value to the understanding and resolution of many social, economic, and environmental problems (Vinogradov 1981, 1984; Mamay 2008; Rafaela et al. 2009; Fichera et al. 2012).

At the initial stage of working were selected cloudless and slightly cloudy scenes close by shooting date (Fig. 5). The data were processed using the software complex ERDAS 2013. The geometric and radiometric correction, layer stack, and preparation of seamless mosaics including color balancing were made. Further, the region of interest from the complete scenes of images was cut out (Fig. 6).

Automated classification was carried out in two stages. In the first stage a mask of agricultural land was created, because the classification problems associated with the separation of this land cover class from others due to the overlap of spectral signatures. Agriculture mask was created by calculating the normalized difference vegetation index (NDVI) (Fig. 7) and the selection of values for open soil (shooting date was specially chosen for the time when the fields are free from crops). In the second stage, the unsupervised classification of images—algorithm Iterative Self-Organizing Data Analysis Technique (ISODATA) using the obtained agriculture mask was realized. Validation of the classification reliability for water bodies was carried out using the modified normalized difference water index (MNDWI) (Fig. 8) (Xu 2006).

The classification resulted in three land cover maps corresponding to the shooting dates (Fig. 9). Four land cover classes were allotted: W—water body, AS—agriculture and settlement, F—forest, and GSW—grassland, steppe, and wetland. The obtained land cover maps further were analyzed in the software package QGIS Desktop 2.10, Modules for Land Use Change Simulations (MOLUSCE) (http://hub.qgis.org/projects/molusce). According to the analysis results, we compiled the change matrix (Ramachandra et al. 2012; Areendran et al.

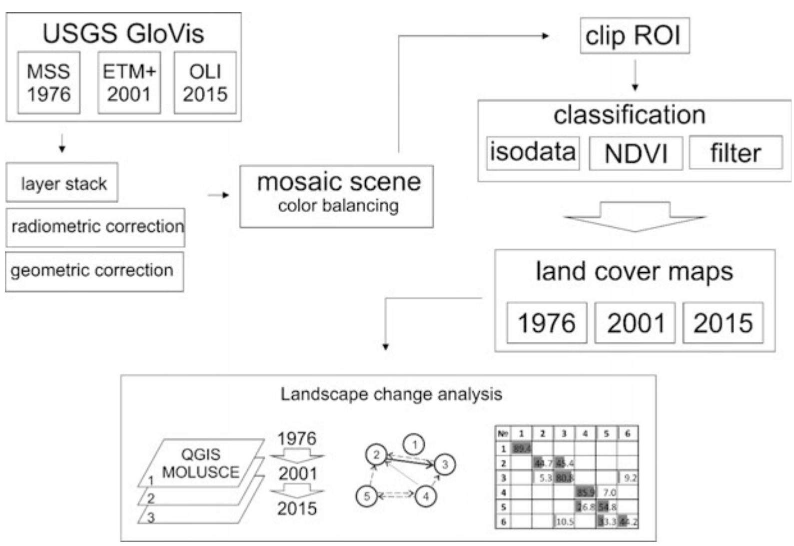
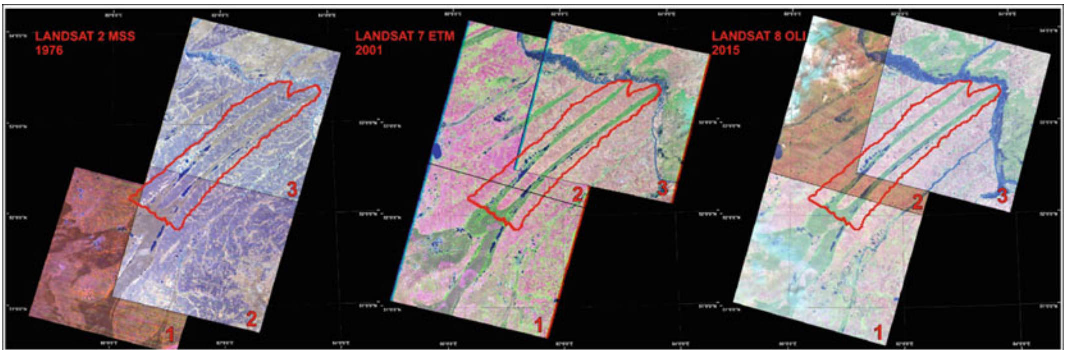


Fig. 4 Flowchart of the remote sensing data analysis



Satellite	Sensor	Scene	Date	Path	Row
Landsat 2	MSS	1	1975.08.14	161	024
		2	1976.05.09	160	024
		3	1976.05.09	160	023
Landsat 7	ETM	1	2001.05.25	149	24
		2	2001.05.25	149	23
		3	2001.05.02	148	23
Landsat 8	OLI	1	2015.05.08	149	24
		2	2015.05.08	149	23
		3	2015.05.01	148	23

Fig. 5 Landsat scenes used in the study

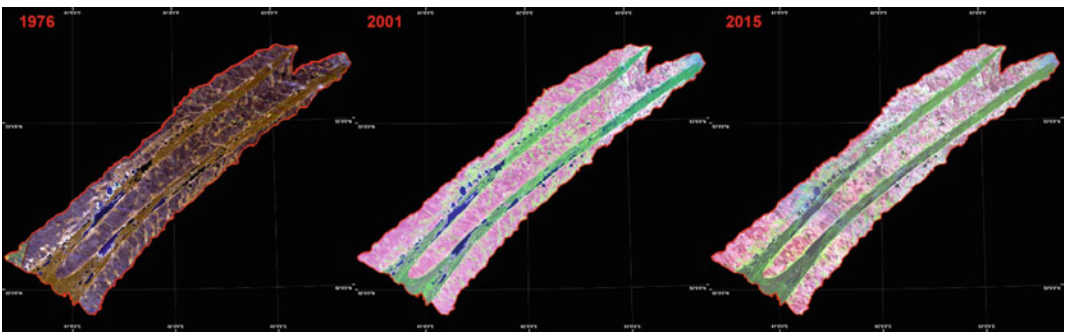


Fig. 6 Region of interest at the Landsat images

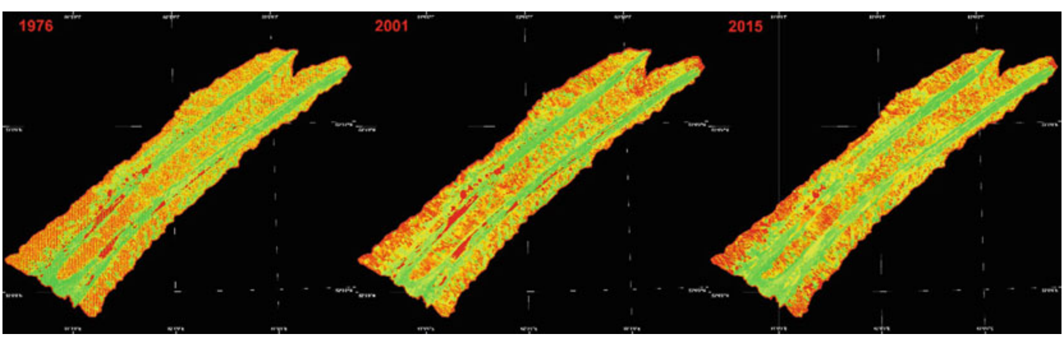


Fig. 7 NDVI maps derived from the Landsat imagery

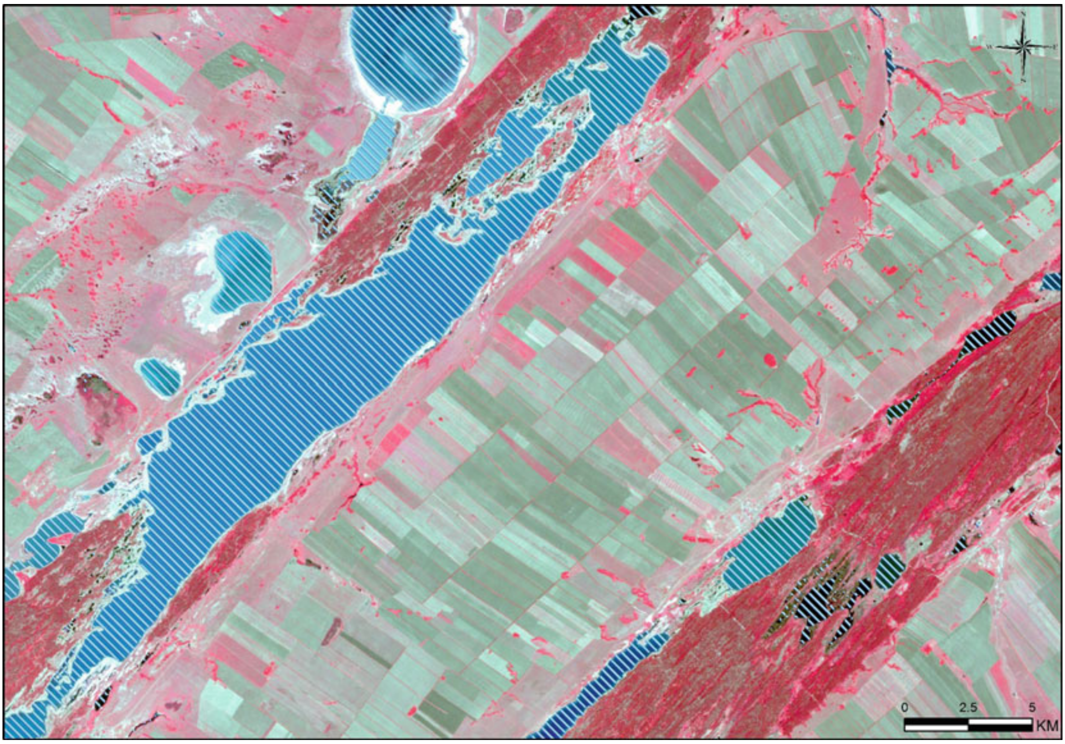


Fig. 8 A fragment of the Landsat image with the overlay of the water body layer obtained using the calculation of MNDWI

2012), which describes the spatial frequency of transitions of different class contours from one to another in the images of different years (Fig. 10).

We are seeing a gradual decline (8%) in the share of AS (mainly arable lands), which primarily transformed into fallows and secondary steppes and to a lesser extent in forests. This process takes place from the time of total plowing (the development of virgin and fallow lands) in 1954–1961 years. The result is a slight ($\Delta A = +1$) increase of steppe graminoids (*Stipa* spp., *Festuca* spp.) activity due to the overgrowth of fallow lands. To a lesser extent, this process has touched herbs (forbs) as a more inert component of steppe plant cover.

Natural herbal (grass) communities (GSW) are the most dynamic class. They largely returned to agricultural use and are covered by forest. The forest generally has slightly changed their area becoming a natural herbal communities and agricultural lands. Such direct and inverse transitions because of the absence of one direction do not allow assessing the changes of geographical activity of the species peculiar to these ecotopes.

Significant changes occur in water body area. They consistently increase the share of its area from 3.08% in 1976 to 5.40% in 2015. However, these changes are not directed because the analyzed images belong to the period of spring floods. This is a reaction to the change in the hydrothermal conditions of a particular time period. Increasing the area of water surface occurs mainly due to the temporary water bodies and overflow of lakes and rivers most often located in extrazonal and intrazonal landscapes (Fig. 11).

The filling of these temporary water bodies depends on the hydrothermal conditions in August–September of the previous hydrological year, the cold period (November–March), and snowmelt period (April–May) of the current hydrological year (Fig. 12). The most important

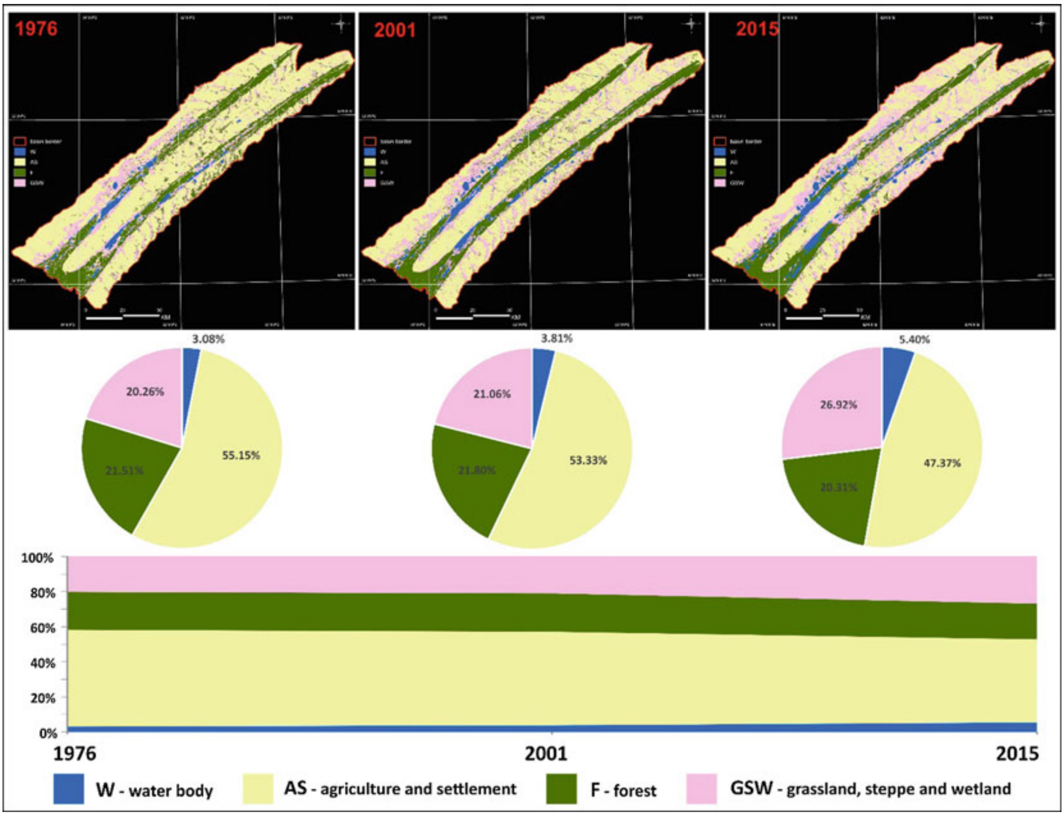
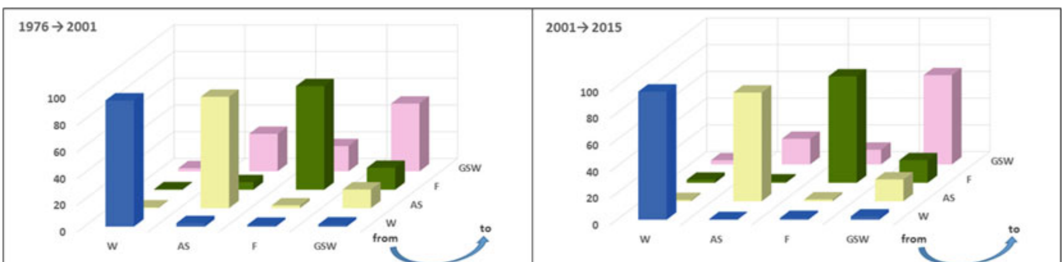


Fig. 9 Area statistics and allocation of land cover changes (%)



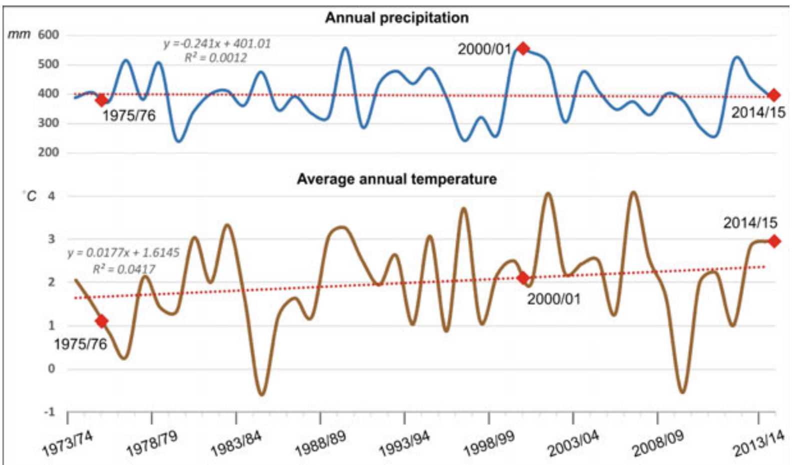
1976 → 2001	W	AS	F	GSW
GSW	2.30	28.09	18.89	50.72
F	0.38	5.66	77.56	16.40
AS	0.55	83.42	2.07	13.95
W	94.46	2.60	1.32	1.62

2001 → 2015	W	AS	F	GSW
GSW	3.11	19.12	10.95	66.82
F	2.29	1.04	79.73	16.93
AS	0.91	81.42	1.37	16.31
W	95.93	0.41	1.25	2.41

Fig. 10 Land cover changes matrix (%) between 1976 and 2001, 2001 and 2015. It shows the change matrix of different land cover classes during periods 1976–2001 and 2001–2015 years. In general, all the land cover classes are relatively stable over time

is the situation before and after a cold period because at this time there is formation of conditions for transformation of winter precipitation into surface and ground water runoff. In 1975, the relatively dry autumn contributed to the fact that soils were poorly saturated with moisture. Cool April (average temperature +2.9 °C) ensured a smooth process of snow melting. The result was a significant decrease of the moisture received by surface water bodies.

Fig. 11 Changes of water body area



		Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Nov-Mar	Apr	May
1975/76	*pr., mm*	30.4	36.5	29.7	39.1	19.1	14.6	42.8	17.3	132.9	13.4	9.9
	t_{avg}, °C	15.8	11.1	2.5	-9.0	-16.7	-13.5	-18.1	-10.9	-13.6	2.9	12.2
2000/01	*pr., mm*	91.2	25.0	48.4	41.3	54.7	38.4	23.1	21.4	178.9	41.3	42.0
	t_{avg}, °C	18.1	10.9	-0.4	-11.7	-12.3	-19.2	-14.8	-3.9	-12.4	3.0	15.9
2014/15	*pr., mm*	45.0	58.0	54.0	41.7	17.5	23.9	11.8	21.3	116.2	31.9	40.6
	t_{avg}, °C	17.8	8.1	1.4	-8.4	-12.9	-13.1	-12.9	-6.1	-10.7	5.3	13.1

Fig. 12 Meteorological conditions of the considered years using the Rebrikha (southern forest-steppe) station within the study area

Hydrothermal conditions of 2000/01 and 2014/15 were very similar. However, the key distinction is the difference in the intensity of snowmelt, which is largely determined by the April temperatures. April 2015 was more than 2 °C warmer, which contributed to intensive melting of snow cover and rapid increase of water level in reservoirs.

These fluctuations of the water bodies area have no noticeable effect on geographical and landscape activity of species because these periodically flooded areas are adapted to flooding (wetlands). In other words, there are no radical ecotopological changes of the landscape structure during such a seasonal variations. The changes in the activity of plant species of exposed to flooding ecotopes can be recorded in a detailed comparison of specific ecotopes during the stationary and semi-stationary research.

Conclusions

1. Plant species activities are closely linked to the anthropogenic impact on the natural landscapes. Activity changes are different for

various groups (ecological, coenotic, and other) and species.

2. During the period of economic development of the territory, most of native steppe species have very significantly and extremely reduced their activity. It is also true for the species of forest swamps and moist forests. Slight activity changes are peculiar to other groups. The activity of alien species is mostly increased.
3. In the last 40 years, we can observe a slight increase in the activity of steppe graminoids due to the formation of fallow lands and secondary steppes from arable lands, but it hardly touches another herbs (forbs).
4. Seasonal and annual fluctuations in area of water bodies and mutual reciprocating transitions of the main land cover classes have no noticeable effect on the geographical activity of the species in the study area.

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Application of Classification and Regression Trees for Spatial Prediction of Rainfall-Induced Shallow Landslides in the Uttarakhand Area (India) Using GIS

Binh Thai Pham, Dieu Tien Bui and Indra Prakash

Abstract

Landslide is defined to be a mass movement of slope materials from up- to downslope under various geo-environmental conditions. It is well known as one of the most serious geo-hazards causing loss of human life and properties throughout the world. In the present study, we present an application of Classification and Regression Trees (CART) for spatial prediction of rainfall-induced shallow landslides in the Uttarakhand area (India) using GIS. A total of 430 historical landslide locations have been first identified to construct landslide inventory map. In addition, eleven landslide influencing factors (slope angle, slope aspect, elevation, curvature, lithology, soil type, land cover, distance to roads, distance to rivers, distance to lineaments, and rainfall) have been taken into account for analyzing the spatial relationship with landslide occurrences. Moreover, the predictive capability of the CART model has been validated using statistical analysis-based evaluations. Overall, the CART model performs well for spatial prediction of landslides. Its performance is even better than other landslide models (Naïve Bayes and Naïve Bayes Trees). Therefore, the CART indicates as encouraging alternative method which could be used for landslide prediction in landslide-prone areas. The results obtained from this study would be helpful for landslide preventing and combating activities in the study area.

Keywords

Landslides · Machine learning · Classification and regression trees GIS · India

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Introduction

Landslide is defined as a mass movement of slope materials (rocks or soils) from up- to downslope under various geo-environmental conditions. It is well known as one of the most serious geo-hazards causing loss of human life and properties throughout the world. India is one of the most affected countries by landslides in Asia (Pham et al. 2015a), and most of landslides have been observed in Himalayan area (the north part of India) (Mathew et al. 2009). Landslides in this area cause the loss of approximately 1 billion US dollar and 200 fatalities yearly (Saha et al. 2002). Mitigation of damages caused by landslides has been turning into urgent task in India. In general, landslide is complex natural geological phenomena. To understand the mechanism of landslides, it requires the detailed knowledge about the character and magnitude of mass movements and their expected frequency in certain area (Pandey et al. 2008).

Identification of potential landslide-prone region is necessary for future strategic planning related to quicker and safer mitigation programs (Shirzadi et al. 2017). Moreover, hazard managers could use remedial measures in advance to protect stability of slopes in high and very high susceptible regions. For this reason, landslide susceptibility map is a helpful tool that shows the degree of susceptibility of each area against landslides. Geographic information system (GIS) with its good spatial data processing ability is used as standard tool in order to produce this map. In addition, statistical methods are usually utilized to analyze the spatial relationship between a set of geo-environmental factors and past landslide events for spatial prediction of landslides.

Many machine learning algorithm-based statistical methods have been developed and applied for mapping of landslide susceptibility using GIS in many regions over the world during recent decades. Frequent methods include support vector machines (Kavzoglu et al. 2014; Marjanović et al. 2011), artificial neural networks (Choi et al. 2010; Lee et al. 2004; Pham et al. 2015b; Poudyal et al. 2010), logistic regression (Devkota et al. 2013; Ozdemir 2011; Van Den Eeckhaut et al. 2006), and decision trees (Marjanović et al. 2011; Yeon et al. 2010).

Classification and Regression Trees (CART) is also a machine learning algorithm-based statistical method that has been applied widely in many fields such as agriculture (Tittonell et al. 2008), medical (Knable et al. 2002; Royston and Altman 2005), and landslides. For the case of landslides, Felicísimo et al. (2013) applied CART for landslide susceptibility mapping and stated that CART has better performance than conventional decision tree methods. Nefeslioglu et al. (2010) also stated that CART is a promising method for landslide susceptibility assessment. Although CART is an efficient machine learning method, its application in landslide prediction is still rare. Therefore, the main objective of the present study is to investigate and apply CART for spatial prediction of rainfall-induced shallow landslides in the Uttarakhand area (India). For validation of the performance of the CART model, statistical analysis-based evaluations have been utilized in the present study. Other landslide models, namely Naïve Bayes and Naïve Bayes Trees, have also been taken into consideration for comparison.

Methods Used

Classification and Regression Trees

CART was first introduced by Breiman et al. (1984) that is a statistic approach based on building a binary decision tree to classify an object into two classes (landslide or non-landslide). It is quite different from the conventional statistical methods related to illustrating the important variables on the base of the performance of the outcomes. It selects the most useful variable from a set of predicted variables for building classification tree (Lewis 2000). The classification tree using CART can be constructed in four main steps: (1) building tree, (2) stopping tree building, (3) pruning tree, and (4) selecting optimal tree (Loh 2008).

Building tree: The root node that includes all instances in the learning dataset is first generated, and then, the classification tree is constructed by finding the best possible variable to divide the root node into two child nodes using some splitting functions. Each node is assigned to a predicted outcome class (Hess et al. 1999).

Stopping tree building: The tree building process is stopped if only one observation in each child node is remaining, or the splitting process is impossible due to all observations at each child node having the identical distribution of predictor variables, or it reaches the number of tree levels that have been set up by user (Knable et al. 2002).

Pruning tree: The method of "cost-complexity" is used for pruning tree to obtain the appropriately fit final tree. If the change of results in the predicted misclassification cost is less than the change of tree complexity, then the child nodes are pruned away (Lewis 2000). More and more child nodes are pruned away, and simpler and simpler trees are obtained.

Selection of optimal tree: The optimal tree, which has the best fit to learning dataset, results in the highest accuracy of prediction to be selected for classification (Breiman et al. 1984). Cross-validation, which is a computationally intensive method, is selected to validate the procedure for building tree (Breiman et al. 1984). In order to train the CART model, the minimal number of observations at the terminal nodes and the number of folds in the internal cross-validation must be set optimally to obtain the best performance of the CART model. In the present study, these parameters have been optimized using the trial-and- error process. As a result, the minimal number of observations has been set at 6, and the number of folds has been set at 9 to train the CART model.

Statistical Analysis-Based Evaluations

Receiver operating characteristic curve is usually utilized as a quantitative method to evaluate the general performance of landslide models (Pradhan 2010). Moreover, statistical measures, namely positive predictive value, negative predictive value, positive sensitivity, specificity, and accuracy, are often used to evaluate more detail of the performance of landslide models (Pham et al. 2016b; Tien Bui et al. 2016a). In this study, these methods have been adopted to validate the performance of CART for spatial prediction of landslides.

Receiver operating characteristic (ROC) curve is constructed by plotting pairs of two statistical values, namely "sensitivity" and "100-specificity" (Pham et al. 2016c; Tien Bui et al. 2016b). The value of area under the ROC curve (AUC) is usually utilized to validate quantitatively the performance of landslide models. The AUC value differs from 0.5 to 1.0. As the AUC value is equal to 0.5, the performance of landslide models is inaccurate (Pham et al. 2016d). In contrast, if the AUC value is equal to 1.0, the performance of landslide models is perfect. In general, if the AUC value is higher than 0.8, the performance of landslide models is good and acceptable (Pham et al. 2016e).

Positive predictive value is defined as the probability of pixels that are predicted correctly as "landslide." Negative predictive value is defined as the probability of pixels that are predicted correctly as "non-landslide." Sensitivity is the proportion of landslide pixels that are predicted correctly as "landslide." Specificity is the proportion of non-landslide pixels that are predicted correctly as "non-landslide" (Pham et al. 2016f). Accuracy is the proportion of landslide and non-landslide pixels that are predicted correctly. These statistical measures are calculated based on the values obtained from confusion matrix (Manel et al. 2001). Higher values of these indexes indicate better performance of landslide models.

Description of Study Region

The study region is located in Uttarakhand state (India) between longitudes (78°29′01″E to 78°37′06″E) and latitudes (29°56′38″N 30°09′37″N) (Fig. 1). It covers an area of approximately 323.815 km^2. Four main types of land cover have been observed in the study region, namely

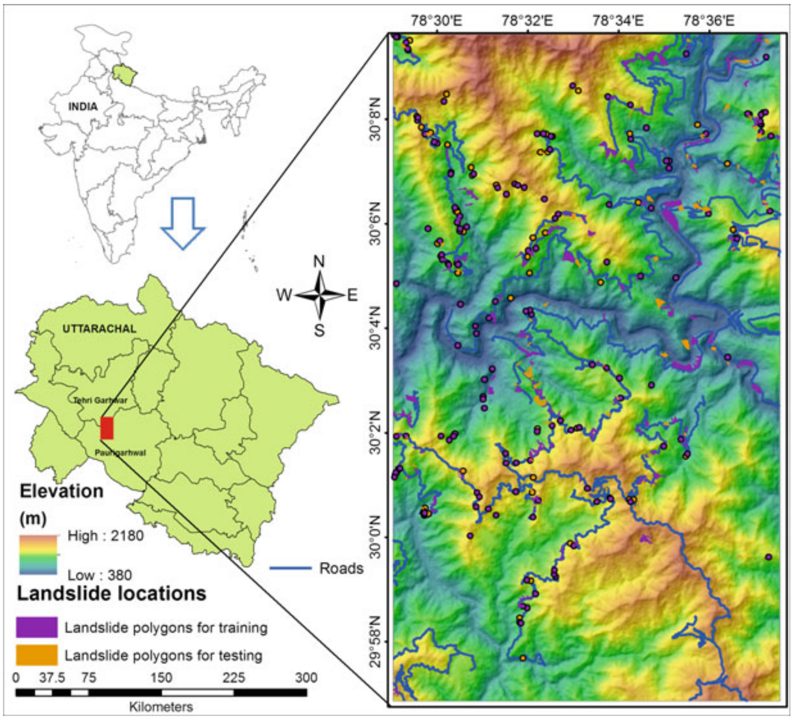

Fig. 1 Location map and landslide inventory

dense forest (31.69% area), open forest (23.36%), non-forest (39.02%), and scrubland (6.67%).

Meteorologically, the study area is situated in subtropical monsoon region with three separated seasons such as summer (October to February), winter (March to June), and monsoon (June to September). Annual average rainfall varies from 770 to 1684 mm. Heavy rainfall often occurs in monsoon season. Annual average temperature ranges from 1.3 °C in winter to 45 °C in summer. Mean humidity in the study region varies from 25 to 85%. Topographically, the study area occupies by hills, mountains, plains, small valleys, mounts, and cliffs. Hilly and mountainous terrain occupies above 90% area of the study region. Elevation differs from 380 to 2180 m (above sea level) with mean elevation of about 1081 m. Slope angles of relief are relatively steep (up to 70°).

Geologically, six main lithological groups outcrop in the study region, namely Blaini-Krol group (boulder bed and limestone), Bijni group (quartzite, phyllite), Amri group (quartzite, phyllite), Tal group (sandstone, shale, quartzite, phyllite, and limestone), Jaunsar group (phyllite and quartzite), and Manikot shell limestone (limestone) (Pham et al. 2015a). Out of these, Baliana-Krol group (30.1% area) and Bijni group (28.1% area) occupy mainly in the study region. There are two main types of soils in the study region, namely fine-silt (26.27%) and loamy (73.73%). Meanwhile, loamy soils have been classified into four subclasses, namely course-loamy (20.1%), skeletal-loamy (42.02%), fine-loamy (8.02%), and mixed-loamy (3.6%).

Data Collection and Preparation

Landslide inventory map is a compilation of the landslide locations which have occurred in the past and present (Pham et al. 2016a). In the present study, this map has first been constructed using landslide locations identified from Google Earth images by tools in Google Earth pro 7.0 software. In addition, Landsat 8 satellite images (15 m resolution) have also been utilized to

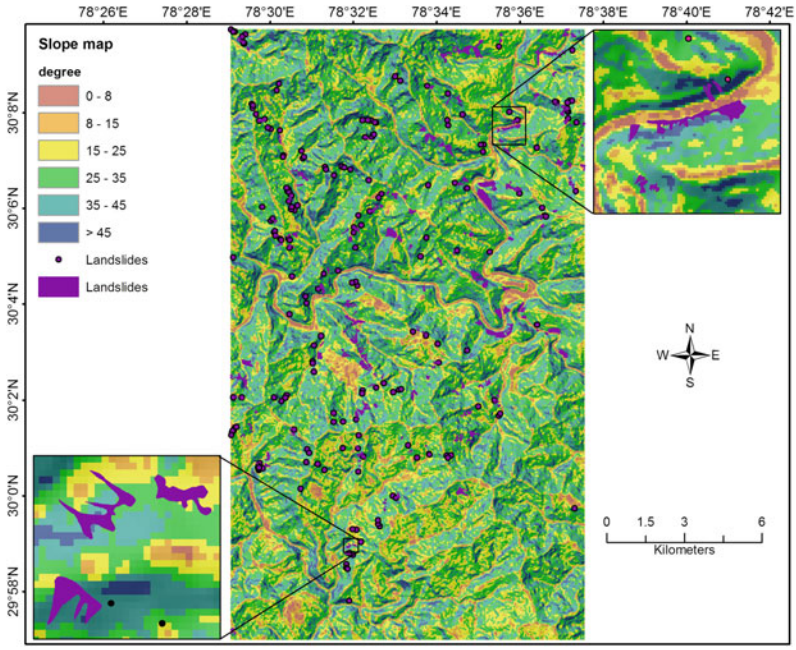

Fig. 2 Slope angle map of the study area

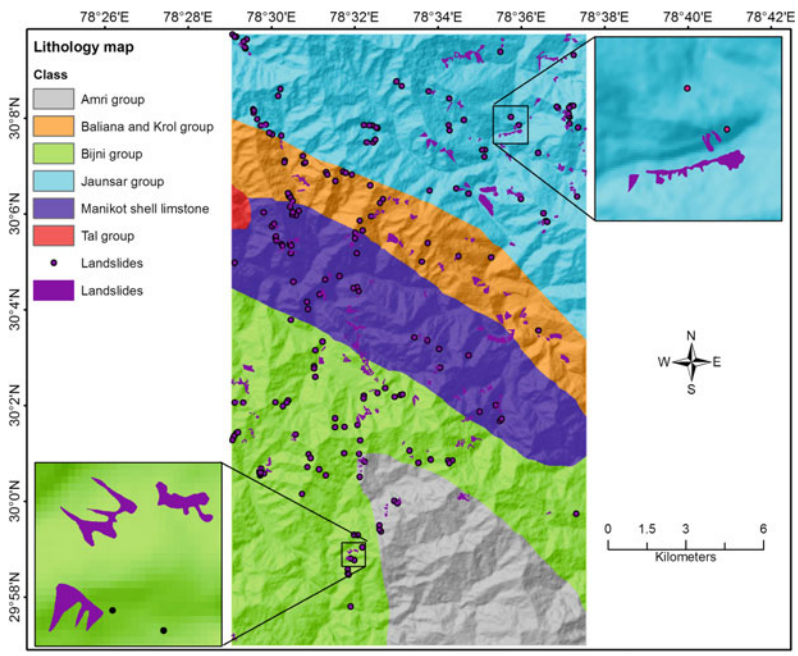

Fig. 3 Lithology map of the study area

identify very large landslide locations in the study region. To validate these landslide locations, extensive field investigation has been carried out in the accessed areas. Furthermore, all information for historical landslides from newspapers and reports has been employed to compare with identified landslide locations. Total of 430 landslide locations have been identified and mapped in the study region (Fig. 1). Out of these, 325 landslide locations are translational type, and 105 landslide locations are rotational type. The largest area of landslide event is about 199,574 m^2. Most of these landslides have been observed beside slope cuttings.

In order to predict landslide spatially, the spatial relationship between historical landslide events and landslide influencing factors has to take into account specifically. In the present study, total of eleven geo-environmental factors have selected as landslide influencing factors for analysis of this relationship (Pham et al. 2015b), namely slope angle, slope aspect, elevation, curvature, lithology, soil type, land cover, rainfall, distance to roads, distance to rivers, and distance to lineaments. Based on the mechanism of landslide occurrences and geo-environmental characteristics of the study region, these factors have been classified into different classes (Table 1). Method of this classification is also based on the analysis of degree of influence of each class to landslide occurrences (Pham et al. 2015b).

Maps of these affecting factors have been constructed as raster data (20 × 20 m pixels) for analyzing process. Specifically, slope angle (Fig. 2), slope aspect, elevation, curvature maps have been generated from digital elevation model (DEM) 20 m extracted from Aster Global DEM. Lithological map (Fig. 3) has been extracted from state geological map on a scale of 1:1000000 (http://www.achec.org.in/wfw/maps.htm). Soil type map has been constructed from state soil map on a scale of 1:1000000 (Pham et al. 2015b). Land cover map has been extracted from state land cover map at a scale of 1:1000000 (http://www.achec.org.in/wfw/maps.htm). Rainfall map has been generated using 30-year meteorological data (1984–2014) collected from Global Weather Data for SWAT (NCEP 2014).

Distance to roads map has been constructed by buffering road sections identified from Google Earth images on high slopes (>10°) in the study region. Distance to rivers map has also been

Table 1 Landslide affecting factors and their classes

No.	Landslide causal factors	Classes
1.	Slope angle (degree)	(i) 0–8; (ii) 8–15; (iii) 15–25; (iv) 25–35; (v) 35–45; (vi) >45
2.	Slope aspect	(i) flat[−1]; (ii) north [0–22.5 and 337.5–360]; (iii) northeast [22.5–67.5]; (iv) east [67.5–112.5]; (v) southeast [112.5–157.5]; (vi) south [157.5–202.5]; (vii) southwest [202.5–247.5]; (viii) west [247.5–292.5]; (ix) northwest [292.5–337.5]
3.	Elevation (m)	(i) 0–600; (ii) 600–750; (iii) 750–900; (iv) 900–1050; (v) 1050–1200; (vi) 1200–1350; (vii) 1350–1500; (viii) 1500–1650; (ix) 1650–1800; (x) >1800
4.	Curvature	(i) concave (<−0.05); (ii) flat (−0.05–0.05); (iii) and convex (>0.05)
5.	Land cover	(i) non-forest; (ii) dense forest; (iii) open forest; (iv) scrubland;
6.	Soil type	(i) course-loamy; (ii) skeletal-loamy; (iii) fine-loamy; (iv) mixed-loamy; (v) fine-silt
7.	Rainfall (mm)	(i) 0–900; (ii) 900–1000; (iii) 1000–1100; (iv) 1100–1200; (v) 1200–1300; (vi) 1300–1400; (vii) 1400–1500; (viii) >1500
8.	Lithology	(i) Amri group [quartzite, phyllite], (ii) Blaini-Krol group [boulder bed and limestone], (iii) Bijni group [quartzite, phyllite]; (iv) Jaunsar group [phyllite and quartzite]; (v) Manikot shell limestone [limestone]; (vi) Tal group [sandstone, shale, quartzite, phyllite, and limestone]
9.	Distance to roads (m)	(i) 0–40; (ii) 40–80; (iii) 80–120; (iv) 120–160; (v) 160–200; (vi) >200
10.	Distance to rivers (m)	(i) 0–40; (ii) 40–80; (iii) 80–120; (iv) 120–160; (v) 160–200; (vi) >200
11.	Distance to lineaments (m)	(i) 0–50; (ii) 50–100; (iii) 100–150; (iv) 150–200; (v) 200–250; (vi) 250–300; (vii) 300–350; (viii) 350–400; (ix) 400–450; (x) 450–500; (xi) >500

constructed by buffering river sections extracted from DEM 20 m on high slopes (>10°) in the study area. Distance to lineaments map has been constructed by buffering lineaments generated from Landsat 8 satellite images in the study area.

Results and Analysis

Evaluation of Predictive Capability of Classification and Regression Trees

Predictive capability of the CART model has been validated using statistical index-based evaluations and the ROC curve method as shown in Table 2, Figs. 4 and 5.

For training the CART model, the number of pixels that have been classified correctly as "landslide" is 94.5% (positive predictive value), and the number of pixels that have been predicted correctly as "non-landslide" is 87.9% (negative predictive value). The number of pixels that have been classified correctly as "landslide" is 88.65% (sensitivity), and the number of pixels that have been classified correctly as "non-landslide" is 94.12% (specificity). The proportion of landslide and non-landslide pixels that have been predicted correctly is 91.20% (accuracy). In addition, area under the ROC curve (AUC) is equal to 0.949. The training results show that the CART model has good degree of fit between input and output for spatial prediction of landslides in the present study.

For validating the CART model, the number of pixels that have been predicted correctly as "landslide" is 71.44% (positive predictive value), and the number of pixels that have been predicted correctly as "non-landslide" is 84.39% (negative predictive value). The number of pixels that have been predicted correctly as "landslide" is 82.06% (sensitivity), and the number of pixels that have been predicted correctly as "non-landslide" is 74.71% (specificity). The proportion of landslide and non-landslide pixels that have been predicted correctly is 77.91% (accuracy). Additionally, area under the ROC curve (AUC) is equal to 0.858. The validating results show that predictive capability of the CART model is good for spatial prediction of landslides in the present study.

Other landslide models such as Naïve Bayes (NB) and Naïve Bayes Trees (NBT) have been utilized in comparison with the CART model in this study. NB is a statistical method based on Bayes' theorem to determine the posterior probability of the class in comparison problems (Amor et al. 2004). It has been applied efficiently for landslide prediction in many studies (Kundu et al. 2013; Pham et al. 2015b). NBT is a hierarchy tree method that is based on hybrid approach of Naïve Bayes and decision tree classifiers (Kohavi 1996). NBT has higher classification accuracy than Naïve Bayes and decision tree (Kohavi 1996). It has been applied successfully for spatial prediction of landslides (Pham et al. 2015a). Based on the analysis of the ROC curve, the performance of these landslide models is shown in Fig. 6. It can be observed that the CART model (AUC = 0.858) outperforms both the NB model (AUC = 0.812) and the NBT model (AUC = 0.832). In addition, the NBT model outperforms the NB model.

Landslide Susceptibility Mapping

Mapping of landslide susceptibility is a last step in spatial prediction of landslides. In the present

Table 2 Performance of the CART model

No	Statistical indexes	Training dataset	Testing dataset
1	Positive predictive value (%)	94.50	71.44
2	Negative predictive value (%)	87.90	84.39
3	Sensitivity (%)	88.65	82.06
4	Specificity (%)	94.12	74.71
5	Accuracy (%)	91.20	77.91

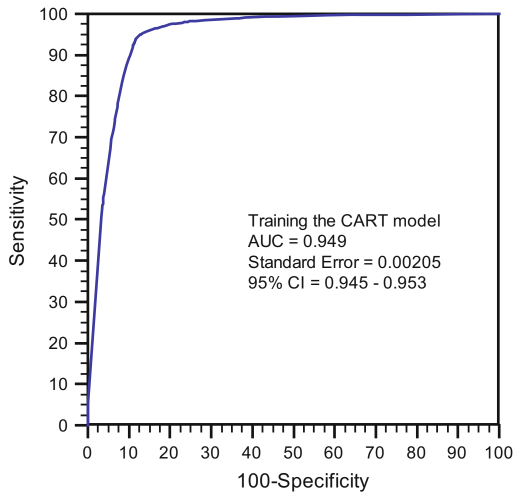

Fig. 4 ROC curve analysis of the CART model using training dataset

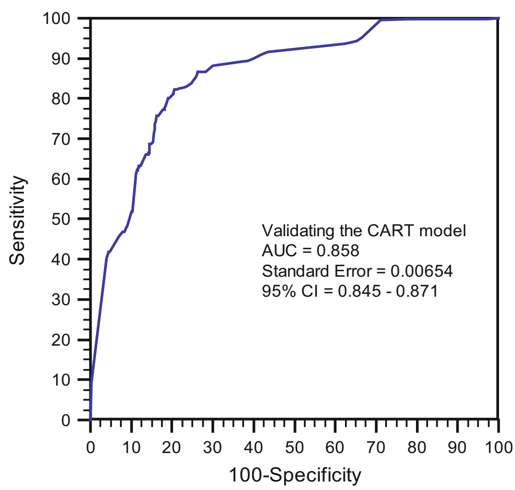

Fig. 5 ROC curve analysis of the CART model using testing dataset

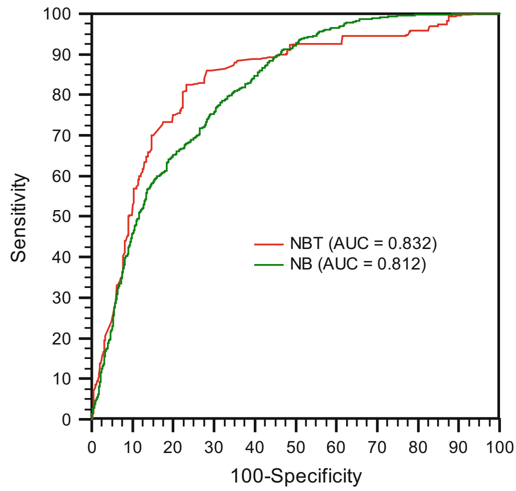

Fig. 6 Comparison of the performance of the landslide models using ROC curve analysis

study, using the CART model, landslide susceptibility map has been constructed in two main steps such as (i) generating landslide susceptibility indices (LSIs) and (ii) reclassifying LSIs (Pham et al. 2016g). At first, LSIs have been generated and assigned for all pixels of whole study area. Susceptible index indicates the degree of susceptibility of each pixel. Second, these LSIs have been reclassified using natural breaks method. Natural breaks method is generally a continuous data classification technique that is used to determine the best arrangement of values into different classes. It is based on minimizing each class's average deviation from average value and maximizing each class's deviation from other mean values of other groups (Chen et al. 2013). Natural breaks method has been utilized in reclassifying LSIs in landslide prediction (Ayalew and Yamagishi 2005; Pham et al. 2015b). Therefore, it is an appropriate technique for reclassification of LSIs in the present study. Based on the classification of natural breaks method, LSIs have been first reclassified into five intervals (Table 3). Landslide susceptibility map of the study area has been then constructed with five susceptible classes, namely very low, low, moderate, high, very high (Fig. 7).

Historical events of landslides have been utilized to validate the performance of landslide susceptibility map in the present study. These landslide locations have been overlaid on landslide susceptibility map to calculate landslide density (LD) on each susceptible class. It has been observed that most of historical landslides have been observed in very high class (LD = 6.3) and high class (2.66). Few landslides have been observed in moderate class (LD = 0.87) and low class (LD = 0.5). A very few landslides

Table 3 Landslide density on landslide susceptibility map

Susceptible class	Number of class pixels	Number of landslide pixels	% Class pixels	% Landslide pixels	Landslide density
Very low	568,517	371	70.22	4.79	0.07
Low	72,566	349	8.96	4.50	0.50
Moderate	24,867	208	3.07	2.68	0.87
High	53,142	1355	6.56	17.49	2.66
Very high	90,578	5464	11.19	70.53	6.30

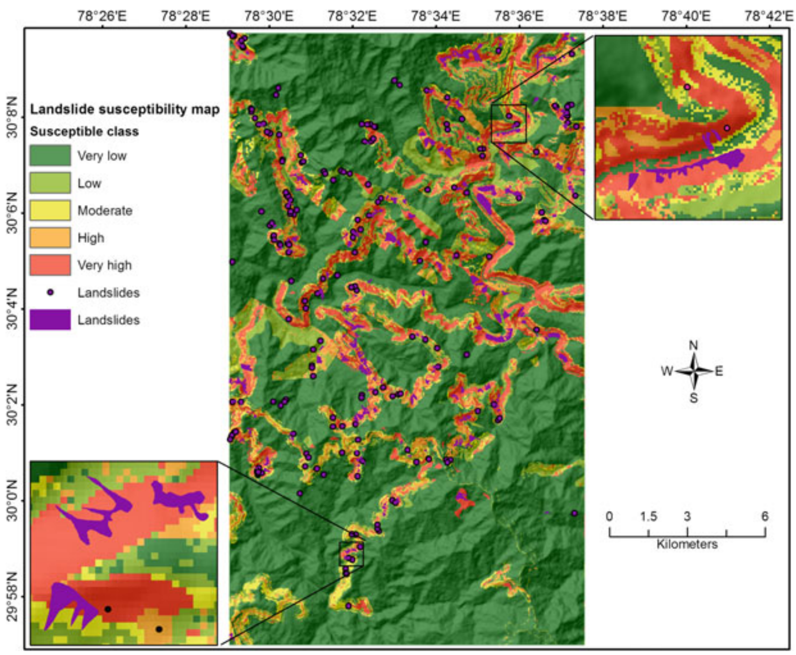

Fig. 7 Landslide susceptibility map in the study area

have been observed in very low class (LD = 0.07). Therefore, the performance of landslide susceptibility obtained from this study is good that could be used for landslide hazard management.

Discussion

In the present study, CART has been applied for spatial prediction of landslides at a part of Uttarakhand state (India). CART is an efficient statistical method in solving classification problems in practice. However, it has been rarely applied in landslide prediction. For applying CART to spatial prediction of landslides, historical landslide events are important and indispensible data can be identified using remote sensing techniques or field investigation (Pandey et al. 2008). In the present study, total 430 historical landslide events have been identified and mapped by interpretation of Google Earth images and then validated by field investigation. In addition, geo-environmental factors that are affected by landslide occurrences in the study area must be determined to analyze the spatial relationship with landslide occurrences (Pham et al. 2015b). Eleven landslide influencing factors have been taken into account for landslide analysis, namely slope angle, slope aspect, elevation, curvature, lithology, soil type, land cover, rainfall, distance to roads, distance to rivers, and distance to lineaments.

Performance of the CART model has been validated using statistical analysis-based evaluations. Other landslide models such as NB and NBT have also been taken into account for comparison. The results show that the CART model has good performance for spatial prediction of landslides in the study area. Even the performance of the CART model is better than other landslide models (NB and NBT).

Main advantage of CART is that it is inherently nonparametric method that can handle highly skewed or multimodal numerical data (Loh 2008). Moreover, no assumptions have to be made during learning process related to the underlying distribution of predictor variable's values. Therefore, it can eliminate analyzing time in determination of whether variables are normally distributed or not for classification (Lewis 2000). Likewise, CART is able to search all possible variables to identify "splitting" variables. It is also efficient in dealing with missing variables. In addition, CART is a fast and simple machine learning technique (Lewis 2000). Meanwhile, NB and NBT are based on an assumption of independence of all parameters and variables that is not really true in landslide problem (Tien Bui et al. 2015). It could be affected by their performance in the present study.

One of the important notices while applying CART for spatial prediction of landslides is that the performance of the CART model depends significantly on the selection of learning parameters for training the model. These parameters include the minimal number of observations at the terminal nodes and the number of folds in the internal cross-validation. Therefore, optimization of these parameters must be carried out to obtain the best performance of the CART model. In the present study, the minimal number of observations has been set at 6, and the number of folds has been set at 9 to train the CART model.

Conclusions

Landslide is one of the most serious geo-hazards causing loss of human life and properties throughout the world. Landslide susceptibility map is a helpful tool in mitigating the damages caused by landslides through land use planning and decision making. In the present study, spatial prediction of landslides has been carried out to produce this map at a part of Uttarakhand state (India). Machine learning method of CART has been applied to analyze the data and modeling.

Based on the result analysis, it can be concluded that CART is a promising method for spatial prediction of landslides that could be used in other landslide-prone areas. Its performance is even better than other machine learning methods (NB and NBT). In practice, landslide susceptibility map obtained from this study could help hazard managers to determine high and very high susceptible areas of landslides. This information will help to take a decision of remedial measures in advance to protect the stability of slopes.

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Part II

Coping with Extreme Events and Disasters

Is Climate Change the Nemesis of Rural Development?: An Analysis of Patterns and Trends of Zimbabwean Droughts

Geoffrey Mukwada and Desmond Manatsa

Abstract

Recurrence of El Nino events has always been associated with losses in agricultural production through widespread crop failure and livestock deaths, resulting in food insecurity and erosion of rural livelihoods. In the whole of southern Africa, food deficits have been recorded during such events, causing acute hunger, undernutrition, malnutrition and nutrient deficiency in most rural communities of Lesotho, Malawi, Mozambique, Swaziland, Zambia and Zimbabwe. Using the case study of Zimbabwe, this paper examines the recurrence of crises arising from severe droughts. Geospatial and temporal analyses of temperature and rainfall are undertaken for the period between 1960 and 2015. Complementary socio-economic data for the same period was drawn from official and news reports, as well as existing literature and internet posts are analysed to determine the impacts of drought in Zimbabwean rural areas. The results show a rise in mean temperature from 1981, and a corresponding exacerbation of drought severity, consequently reflecting the vulnerability of the rural economy to the changing climate. The paper concludes that there is a need for development agencies to build new resilience strategies for rural communities, even in areas that were previously considered to be water surplus regions. However, widespread material poverty, as well as lack of capital investment, hinders efforts to implement such strategies.

Keywords

Climate change · Drought · El Nino · Food insecurity · Poverty Tourism · Zimbabwe

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Introduction

Drought is a serious environmental threat throughout Sub-Saharan Africa, where about 60% of the people are exposed to the hazard (Ngaka 2012). It is one of the most imperious natural hazards threatening economies in southern Africa, where socio-economic development and livelihoods depend on rain-fed agriculture (Meque and Abiodun 2015). Recent assessments by the IPCC suggest that in southern Africa longer dry seasons and variable precipitation threaten food security (Magadza 2010). Drought is a common occurrence in southern Africa.

In Zimbabwe, drought poses serious challenges to rural communities because agriculture is the mainstay of the economy. Over six million indigenous black people live in Zimbabwe's marginal rural lands, termed communal areas, where soils are poor and rainfall is unreliable and where producers have been historically excluded from the bulk of the nations' natural resources, including land (Moyo 2000). Mtisi and Nicol (2003) have noted that as a whole Zimbabwe is a drought prone semi-arid country characterised by a dry winter season and a mid-season drought prone rainy season. Drought, which is usually accompanied by a deficiency in seasonal or annual precipitation, may result in agricultural losses, power outages, economic inflation and reduced urban and rural water supplies (Boken et al. 2005). UNFCCC (2007) observed that developing countries are particularly vulnerable to drought because they find it difficult to adapt socially, technologically and economically due to lack of resources. Zimbabwe is particularly vulnerable to drought because the livelihoods of the majority of its population depend on rain-fed agriculture (Muzari et al. 2013). It has been estimated that more than 60% of the population depends on rain-fed subsistence or semi-subsistence farming for livelihood (Makaudze and Miranda 2010). In recent years, drought has been exacerbated by climate change, with serious implications on the rural economy. This scenario arises from the fact that the impact of climate change on water resources has both direct and indirect effects on the socio-economic and biophysical environments (Kusangaya et al. 2014). Such a situation is already evident in agriculture (Crane et al. 2011), health (Gage et al. 2008), ecosystems and biodiversity (Eriksen and Watson 2009), energy generation (Yamba et al. 2011; Magadza 2000) and human settlements (Magadza 2000), causing loss of life, social disruption and economic hardships (Kusangaya et al. 2014). The chain effects of persistent droughts can shatter an economy or even cause famine and socio-political upheavals in some countries (Boken et al. 2005).

Zimbabwean rural areas are often subjected to load shedding when severe droughts occur. For instance, during the 1991–92 drought Kariba Dam, the only reservoir from which hydroelectric power is generated in the country, recorded drastic recession in water level, consequently reducing the country's electricity generation capacity (Mtisi and Nicol 2003). An analysis of the December to February season climatic data from the Kariba meteorological station indicated that there was a warming of 5 °C per century and a decreased precipitation of 190 mm per century within the Zambezi River Valley (Magadza 2010).

However, the notion of drought occurrence due to climate change is not necessarily shared by all researchers. Consequently, two diametrically opposed viewpoints have recently emerged regarding the relationship between climate change and development in Zimbabwe. On the one hand is the argument that global warming is responsible for climate change and recurrence of drought in the country. Opposed to this view is the argument that even refutes the notion of climate change altogether. Even though this view recognizes the high inter-annual variability of rainfall, it maintains that no change due to global warming has yet been statistically detectable (Lørup et al. 1998). Nevertheless, climate change has the potential to worsen water supply and demand pressures throughout southern Africa (Kusangaya et al. 2014).

In Zimbabwe, drought poses a threat to the economy because of its predominant agrarian nature (Moyo 2000). Moyo (2000) notes that the Zimbabwean economic structure restricts rural incomes and the expansion of domestic markets because over 60% of the rural people are poor and cannot afford basic health and educational services. It is estimated that about 65% of the country receives less than 500 mm of rain per year while rainfall variability is common due to El Nino (Nyakudya and Stroosnijder 2011; Mavhura et al. 2015), consequently leading to reduced crop yields and increased food insecurity. Often, in Zimbabwean semi-arid agricultural systems, reduction in crop yields is caused by intra-seasonal dry spells that occur every three out of four seasons, a situation which Enfors and Gordon (2008) attributes to inadequate water supply and a wide range of other constraints that make the small-scale agricultural system a highly uncertain food and income source.

Focusing primarily on severe droughts, this paper contributes to the growing body of knowledge on challenges associated with climate change and drought in southern Africa by drawing from literature, empirical climatic data, and complementary socio-economic data from official and news reports, as well as internet posts. This paper focuses on two key objectives. The first objective is to use empirical climatic data to investigate patterns and trends of drought in Zimbabwe and determine if these patterns and trends are linked to climate change. The second objective is to assess the extent to which Zimbabwe's rural economy is susceptible to drought.

Methodology

Geospatial and temporal analyses of climatic conditions are undertaken for the period between 1960 and 2015. Rainfall and temperature data are derived from the Climate Research Unit global dataset available on the website http://catalogue.ceda.ac.uk/uuid/. SPI and SPEI drought severity indices were derived from the CSIS website http://sac.csic.es/spei/index.html. Normalization of the two drought severity indices was done, and the differences between the normalized values were used to assess the contribution of temperature to drought. The cumulative sum (CUSUM) technique, which is basically the summation of the residuals of the respective time series, was used to detect shifts in the data. The empirical evidence to ascertain the increase in the severity of seasonal drought was drawn for the period from October to March between 1960 and 2015.

Content analysis of official and news reports as well as historical records within the existing body of literature was analysed for the same period to determine if there is any relationship between occurrence of drought and the socio-economic challenges experienced in Zimbabwean rural areas. This paper addresses two critical questions. The first question is about whether patterns of drought in Zimbabwe are related to climate change, while the second is about determining the impact of drought on the country's rural economy.

Results

Spatio-Temporal Drought Trends in Zimbabwe

In Fig. 1, we present the CUSUM time series of two drought severity indices, the SPI and SPEI for Zimbabwe. The former is constructed using rainfall data only whilst the latter takes into consideration the impact of temperature on reducing the available water through evapotranspiration. We note in Fig. 1a that although the SPI CUMSUM does not indicate a trend in the drought severity, the SPEI CUSUM index demonstrates a negative trend which signifies an increase in the drought severity. However, the widening in the difference becomes more conspicuous from 1981. Since the difference between the two drought severity indices is only in temperature, we show in Fig. 2b that the robust widening from 1981 is most probably because of the shift in maximum temperature that started the same year. The maximum temperature shifted by about 1 °C from an average of 27.2–28.1 °C, which is also quite robust in the superimposed SAT_{max} CUSUM index (broken line). This provides clear evidence that it is the change in the maximum temperatures which increased the severity of the droughts from 1981.

The implications are that the available water resources are constrained despite an insignificant change in the rainfall amount received during the study period.

Figure 2a shows that the difference in the averaged SAT_{max} between the pre- and post-1981 epochs has not been uniform throughout the country. An increase of up to 1.4 °C has been experienced over the western most part while north-eastern areas experienced warming of less than 0.7 °C. This has resulted in the north-eastern parts of the country, as shown

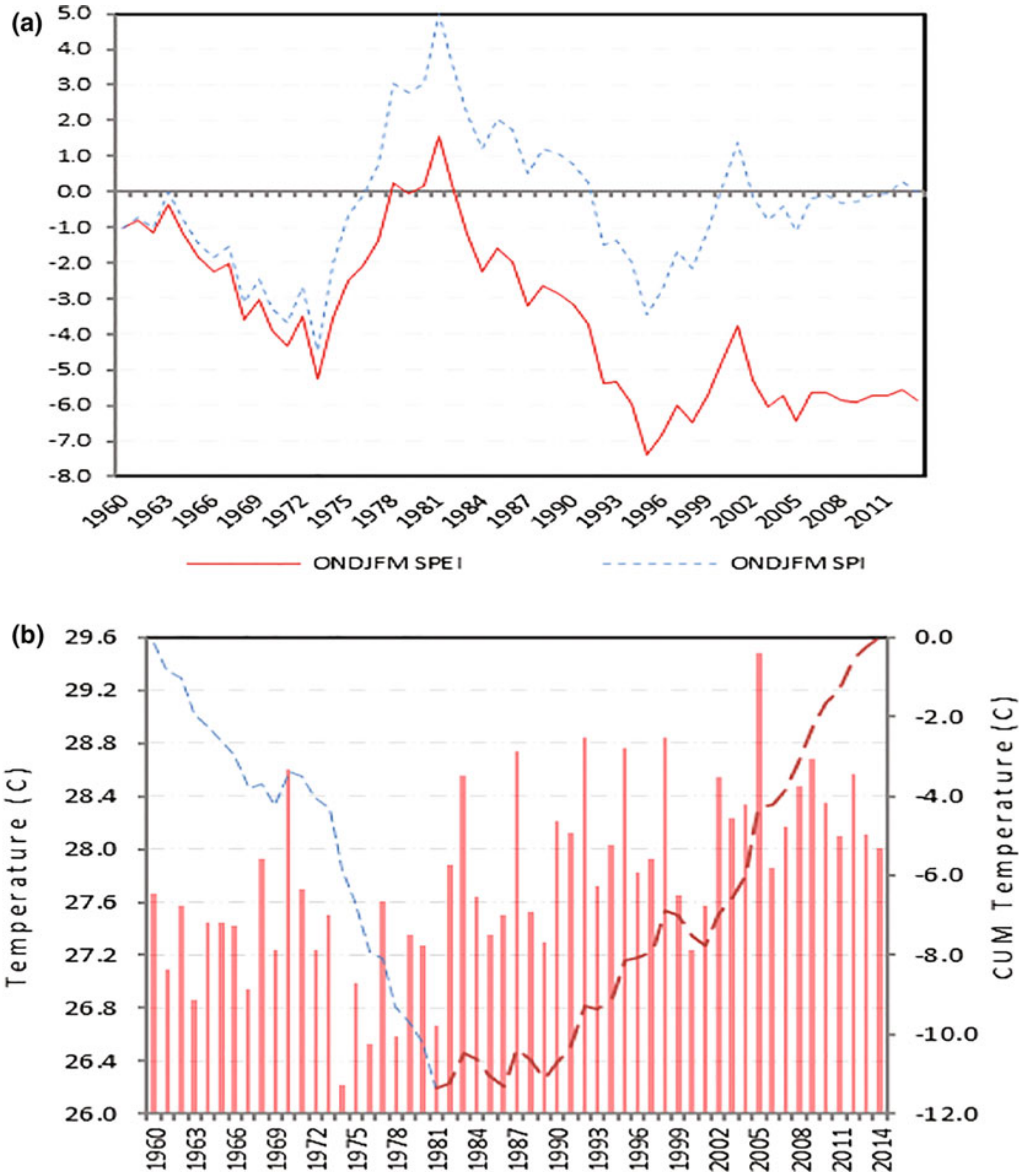

Fig. 1 Temporal manifestation of the **a** CUSUM indices for the SPI (*broken line*) and the SPEI (*solid line*) **b** SAT_{max} (*bars*) with its corresponding CUSUM index superimposed (*broken line*). That data are averaged over Zimbabwe for the period October to March from 1960 to 2014

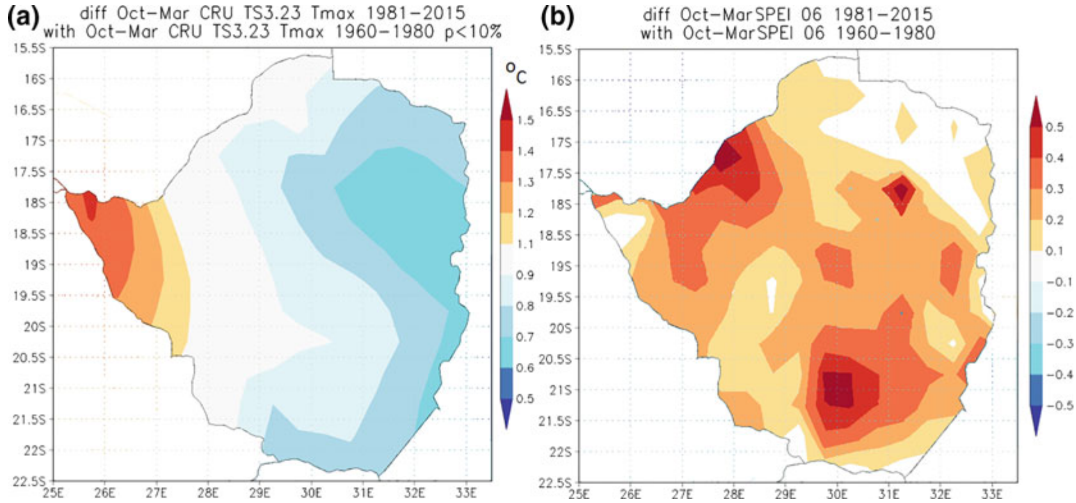

Fig. 2 Spatial distribution of difference in **a** SAT $_{max}$ and **b** SPEI between the post- and pre-1981 epoch for the period October to March during 1960 to 2014. *Shaded regions* are significant at 90 and 80% confidence levels for **a** and **b,** respectively

by the SPEI index, demonstrating moderate intensification of the severity in drought whilst greater severity is experienced over the south-west. Thus, regions which generally have less rainfall are those which have warmed more and are tending to lose more of the available water through excessive evapotranspiration, causing an increased severity in droughts.

The Current State of the Zimbabwean Economy

The decline of the Zimbabwean economy in recent years has been attributed to a variety of causes, including unsuitable policy environment, political strife, instability of the financial sector and drought. These multiple causes have been highlighted in a joint report by the AfDB, OECD and UNDP, entitled “African Economic Outlook”. In this report, it has been shown that the growth of the Zimbabwean economy has slowed to around 3% in 2014 and was expected to register a marginal improvement in 2015 and 2016, due to persistent de-industrialization and the growing of the informal economy. Other problems that have been cited in the report include lack of appropriate structural reforms to improve the business environment, the need to achieve a sustainable current account balance, as well as the need to reform public enterprises. However, the economy is in a general state of recovery, compared to the period between 1999 and 2008. This recovery is most noticeable within the rural economy, partly due to the significant increase in tobacco production in 2014, as the number of growers and acreage increased, and the firming in producer prices which boosted the main production crops such as maize, tobacco and cotton, thus contributing to the agricultural growth of 3.4% that was expected in 2015.

Despite the recovery of the agricultural sector food insecurity among households across the country remains high due to the combined effect of recurrent droughts, occasional floods and high unemployment (AfDB, OECD and UNDP 2015). The 2014 rural livelihoods assessment report published by the Zimbabwe Vulnerability Assessment Committee (ZimVAC) estimated that a third of Zimbabwe’s children are stunted due to malnutrition, while 6% of the rural population required food assistance in the first quarter of 2015. Results from the ZimVAC 2015 assessment indicate that 16% of Zimbabwe’s rural households (approximately 1.5 million people) required food aid during the

2015/2016 season (The Independent: http://www.theindependent.co.zw/2015/11/20/drought-will-devastate-economy/).

This situation further worsened in 2016. When addressing the opening ceremony of the 26th Ordinary Session of the Assembly of the African Union (AU) at the African Union headquarters in Addis Ababa on 30 January 2016, Zimbabwe's President, Robert Mugabe, declared a state of disaster in Zimbabwe's rural areas, where 26% of the population (about 2.44 million people) needed urgent food assistance because of drought. Due to drought, the country needs to import about 700,000 tonnes in order to avert starvation (Technology, 5 February 2016: http://www.reuters.com/article/us-africa-drought-zimbabwe-idUSKCN0VE0HA).

Similar improvements were expected in tourism. With the launching of a new tourism policy in July 2014, there has been an increase in both domestic and international visitors to Zimbabwe. However, the success of tourism promotion projects depends on radical changes in tourism marketing. A typical example of this approach was the establishment of the Kavango–Zambezi Transfrontier Conservation Area (KAZA TFCA) Univisa pilot project between Zimbabwe and Zambia, on 28 November 2014, which allows uninterrupted movement of tourists between the two countries. The newly launched policy highlights the importance of wildlife resources in tourism recovery plans in Zimbabwe.

During the past decade, there has been a huge debate about the collapse of the Zimbabwean economy, with some skeptics arguing that unfavourable conditions resulting from the land reform programme that the government launched in 2000 was responsible for the demise of the national economy, while others have identified drought recurrence as the primary cause of economic failure. Both groups of scholars have provided convincing evidence about the conditions that have contributed to the collapse. Issues raised in the debates range from political ones like poor governance and a hostile socio-political environment, to climate variability and change. In Zimbabwe, most previous research on drought has been centred on agriculture due to its importance to the national economy. However, traditionally Zimbabwe's rural economy has also depended on mining and tourism, and to some extent manufacturing, as shown by the results of this research study.

Impact of Climate Variability and Drought on Rural Tourism

The exposure and vulnerability of the Zimbabwean economy to drought cannot be doubted. The greatest threat posed by climate variability on tourism arises from drought. Drought leads to the alteration of the hydrological regime of rivers and the volume of water available in inland lakes, thus undermining water related tourism activities, especially water sports. Receding water levels means reduced water flows downstream, thus affecting aquatic, riverine and riparian ecosystems, in most cases leading to massive deaths of wildlife. In 2016, Zimbabwe launched a wildlife auction in order to prevent large-scale decimation of wild animals, including the "big five", that is elephant, buffalo, lion, leopard and rhino. In the past, drought episodes have caused massive deaths of wildlife, even in nature reserves, leading to reduced numbers of tourists visiting these areas.

For instance, Dudley et al. (2001) reported of high mortality of the African elephant (*Loxondota africana*) in the Hwange National Park, one of the largest wildlife tourism destination in Zimbabwe, during the 1928, 1933, 1960–61, 1968, 1970–71, 1980–84, 1987 and 1993–95 drought years, despite the vagility and large home ranges of the species. Using quantile regressions, Chamaillé-Jammes et al. (2007) have shown that in Hwange National Park droughts have worsened in recent years. Considering that tourism is only starting to recover after a decade of decline due to political turmoil and also that it is the fastest growing sector of the economy, unfavourable conditions resulting from drought do not augur well for the industry.

Impact of Drought on Manufacturing and Rural Linkages

While the rural economy is largely agricultural, the inter-linkages between agriculture and manufacturing create self-reinforcing feedbacks that pose a threat to rural livelihoods. For instance, drought leads to shortage of raw materials for the manufacturing industry, and subsequently, the downscaling of investment in agro-industrial activities and reduced production of agricultural inputs, which in turn leads to reduced acreage and loss of rural income. There are several instances when agricultural productivity has been undermined by shortage of inputs, even when environmental conditions are favourable to agriculture. A depressed manufacturing sector suppresses the rural economy, making its recovery slow.

Impact of Drought on Agriculture

As noted earlier, Zimbabwe's economy is largely agriculture based. This makes it vulnerable to any unfavourable environmental changes that have an impact on farming activities, whether such changes are natural or anthropogenic. In this chapter, we investigate the extent to which climate change and variability have affected the country, in line with our earlier stated objectives. There is evidence from existing literature showing that concerted efforts have been made to analyze the environmental conditions associated with drought in order to reduce risks associated with this hazard. For example, Manatsa et al. (2010) used SPIs to assess the multidimensional aspects of agricultural drought in Zimbabwe while Unganai et al. (2013) used SPIs to tailor the seasonal climate forecast for climate risk management in the rain-fed farming system in Zimbabwe.

Zimbabwe's agricultural sector comprises four sub-sectors, the Large-Scale Commercial Farming (LSCF), Small-Scale Commercial Farming (SSCF), resettlement and communal farming sectors, each of which is affected differently by drought. Following Zimbabwe's land reform which led to the displacement of white commercial farmers, the LSCF sector has become undercapitalized. The former white-owned farms that constituted this sector were allocated to black farmers on ninety-nine lease contracts. The lease agreements cannot be used as collateral, making banks reluctant to issue loans for farm improvement. The newly emerging commercial farmers, therefore, fail to secure the financial resources that are required to procure the irrigation equipment that farmers need in order to cope with drought. Consequently, the potential for groundwater resources development has not been fully developed, making the farmers vulnerable to drought. Massive job losses are often reported in the aftermath of a major drought. The SSCF commercial factor is affected in a similar way. The communal and resettlement farmers face the added disadvantage that they depend on livestock for draught power and social security. Limited capacity makes it difficult for most small-scale farmers in these two sectors to recover. Often, they rely on livestock sales as insurance against food shortages and to meet other household needs. Losses of livestock and poor yields resulting from droughts undermine this social security. For instance, Alexander and McGregor (2000) report how droughts have led large parts of Lupane and Nkayi's population in the northern parts of Zimbabwe to become totally dependent on state-supplied drought relief and grain loans.

The failure of agriculture creates several socio-economic complications. First, large quantities of food have to be imported, causing a strain on the GDP. For instance, it was estimated that 1.4 million people required food aid during the 2011–2012 agricultural period as a result of drought induced chronic food insecurity (Mukwada and Manatsa 2013). In 2016, about four million people needed food assistance as a result of drought. Food imports pose serious opportunity costs for the country, including the rural development projects that have to be foregone. However, the food for work projects which government uses to harness rural labour for the construction of roads and bridges or for undertaking environmental rehabilitation exercises in rural areas is the exception because it allows optimization of use of idle labour which is drawn off the farms during periods of drought.

In Zimbabwe, increased frequency of drought has been a noticeable phenomenon during the past three decades. For instance, high recurrence of drought has been most evident between 1981 and 1992. During this period, the average amount of rainfall received was below a thirty year average, with the 1991–92 season experiencing the most widespread and most severe drought in the 20th century (Bird and Shepherd 2003; Meque and Abiodun 2015). Mtisi and Nicol (2003) reported of household annual maize production dropping from an average of three tonnes in 1991 to less than half a tonne in 1992, with yields similarly dropping from over two tonnes per hectare in 1991 to 47 kg per hectare in 1992. Similar reports were made by Manatsa et al. (2011), who showed how maize yields varied with satellite rainfall estimates. Maize is the staple food in Zimbabwe. Mtisi and Nicol (2003) reported that during the 1991–92 period more than 40% of Zimbabwe's population was affected by drought, which reduced the country's GNP by up to 12% and raised inflation to about 48% at the drought's height. As noted by Mtisi and Nicol (2003), nearly 40% of the water points dried up and at least 600,000 head of cattle had to be slaughtered due to shortage of browse and water. Livestock censuses have revealed that there has not been any significant increase in the number of livestock following the 1981–83 and 1991–92 severe droughts (Lørup et al. 1998).

Discussion

This paper addressed two objectives. The first is related to the investigation of patterns and trends of drought in Zimbabwe and how the patterns and trends are linked to climate change. The second was about the assessment of the extent to which Zimbabwe's rural economy is affected by drought. As demonstrated by the results of this research, climate change is evident in Zimbabwe. In recent years, climate change has been associated with a high frequency of drought recurrence. In Zimbabwe, drought conditions largely prevail during El Nino events. Thus, drought is highly influenced by the Southern Oscillation climate mode. The results also show that the severity of drought has worsened in recent years, though the 1991–92 is perhaps the most severe among drought events recorded in recent decades. It is evident that Zimbabwe's rural economy is highly susceptible to drought. This is because of the nature of the linkages that exist between rural livelihoods and the natural environment. The majority of rural Zimbabweans rely on primary economic activities for livelihood. These activities directly depend on the state of the natural environment, including access to water resources.

As noted in the foregoing discussion, shortage of water due to drought has a direct impact on agriculture and tourism, which are the mainstay of employment and access to good sanitation and food security in most rural communities. An example of an indirect effect of drought relates to situations when expenditure on food imports rises in attempts to avert starvation, consequently depriving the national economy of resources that could otherwise be invested in rural development. The shrinking of the country's GNP also results in reduced rural investment, while the reduction of the national livestock head creates problems such as loss of draught power and livelihood security. Boken's et al. (2005) argument that persistent droughts generate chain effects that have the capacity to shatter an economy is valid in this context. In the case of Zimbabwe, recurrence of drought has worsened rural poverty due to the widespread devastating effects that it has caused in all sectors of the rural economy, including agriculture and tourism, which are important for rural livelihoods.

Considering that most of the people in rural areas are not formally employed, but depend on subsistence farming as their only source of livelihood, any reduction in crop yields, for instance cash crops such as cotton, tobacco and sugar cane, and recurrent livestock losses worsen their state of deprivation and deepen material poverty. In order to reduce poverty, government must adopt policy measures that enhance the resilience of rural communities so that their vulnerability to drought is lessened. Government should promote investment in alternative sources of livelihood, particularly those that enable rural communities to depend less on water. In the agricultural sector, research should focus on how drought resistant small livestock, which require less water, can be promoted as an alternative livelihood strategy for the drier parts of the country.

Several agriculture based resilience boosting strategies have previously been recommended, including adoption of drought resistant food crops that are suitable for drought prone areas such as cowpeas (*Vigna unguiculata*), finger millet (*Eleusine coracana*) and sorghum (*Sorghum bicolor*) (Mukwada and Manatsa 2013). Reliance on these less sensitive crops will enable farmers to adopt more water-efficient cropping systems, including conservation agriculture, to mitigate the effects of climate change (Thierfelder and Wall 2010), while changing crop varieties and planting dates are alternative options (Gwimbi 2009; Lobell et al. 2008). However, there is little evidence suggesting that it will be easy for the country to adopt these strategies. As noted by UNFCCC (2007) developing countries become vulnerable to drought because they find it difficult to adapt socially, technologically and economically due to lack of resources, of which Zimbabwe is no exception.

Conclusion

As noted in the above discussion, Zimbabwe's climate is highly variable. Evidence of climate change is reflected in increased drought severity since 1981 which coincides with a shift to warming in the SAT_{max}. It is noted that the increase in drought severity occurred despite lack of a significant trend in the seasonally averaged rainfall for the country. Data from official and news reports, internet posts and the literature that was reviewed indicates that the Zimbabwean economy is highly susceptible to drought. In Zimbabwean rural areas in particular, shortage of water resources arising from drought is the reason why climate change is the nemesis of development, though there are numerous socio-economic and political factors that undermine economic growth in the country as a whole. From the foregoing discussion, it can therefore be concluded that the observed decrease in available water resources due to increased severity of droughts necessitates a corresponding radical policy shift towards alternative livelihood strategies that depend less on water resources.

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Entering the New +2 °C Global Warming Age and a Threat of World Ocean Expansion for Sustainable Economic Development

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Abstract

Within the framework of its adaptation strategy to climate change, the EU adopted the upper limit of 2 °C (UNFCCC, Cancun 2010) as an allowable increase concerning the average air temperature of the planet. This decision aims at compulsorily reducing the most serious risks from climate change. The UN Conference on Climate Change (UNFCCC COP21 2015) emphasizing the holding of the increase in the global average temperature to well below 2 °C above pre-industrial levels by reducing emissions to 40 Gt or to pursuing efforts to limit the temperature increase to 1.5 °C. Taking into an account the COP21 climate change strategy, we consider five significant cases. The first one for the current climate conditions (corresponds to a 0.8 °C global warming above the pre-industrial level), the model based on logistic equation provides a solution according which, within the next 95 years, the sea level will rise up to +5 m and stabilize at +6 m level within a 150-year relaxation time. The second one, if global warming could be reduced of 28.5 times to the value of global average temperature 0.028 °C, the sea level would stabilize to the current value of 0.21 m. The third—if the global average temperature will increase to 1.5 °C above the pre-industrial era, this will lead to an inevitable rise of the global sea level by +11.25 m. The fourth—if Earth's global average temperature increases to 2 °C above

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the pre-industrial era, this will accelerate the sea-level rise up to +15 m. The fifth—a realistic level of the global average temperature increase to 3 °C will lead to sea-level rise (SLR) by +22.5 m. This can happen from 100 years up to 250 years and can be associated with carbon dioxide emission and methane blowout from the Ocean. Taking into an account the Max Planck Institute for Chemistry climate model based on dust emission in atmosphere with +4 °C Global Warming up to 2050 year, we can predict the very fast SLR up to 30 m. Exceeding the critical level of global average temperature +1.30(6) °C or the +9.8 m SLR will destabilize the Earth climate system and could provoke falling in the next Ice Age. This value is 1.53 times less than the +2 °C Global Warming level adopted in Paris (UNFCCC COP21 2015) as acceptable for sustainable economic development. Antarctica ice mass loss and Greenland ice mass loss are going with the rate of 2.03 and 1.74, within five-year period (August, 2010–2015) and estimated as total 589.9 Gt in 2016 that will contribute SLR the 1.628 mm per year. The main question is can the national mid-century strategies for the transition to low-emission economies stop the SLR before it will be too late.

Keywords
Climate change · Global warming · Sea-level rise · Disaster risk reduction
Economic losses

Introduction

Within the framework of its adaptation strategy to climate change (An EU Strategy on Adaptation to Climate Change 2013, p. 5), the EU adopted the upper limit of 2 °C (UNFCCC, Cancun 2010) as an allowable increase concerning the global average temperature of the planet. This decision aims at compulsorily reducing the most serious risks from climate change.

The UN Conference in Paris on Climate Change (UNFCCC COP21 2015) emphasizing the holding of the increase in the global average temperature to well below 2 °C above pre-industrial levels by reducing emissions to 40 Gt or to pursuing efforts to limit the temperature increase to 1.5 °C. The UN Conference on Climate Change in Paris (UNFCCC COP21 2015) mentioned a realistic level of the global average temperature to well below 3 °C above pre-industrial levels by reducing emissions of greenhouse gases (GHG) by all negotiated countries. If China and USA, the main sources of GHG emission, will join the Paris 2015 COP21 agreement, then it would be possible to limit the temperature increase to 2 or 1.5 °C above pre-industrial levels.

The rate of Global Warming (GW) is following the relation of GHG concentration. The Previdi et al. (2013) made the estimation of the climate sensitivity for doubled CO_2 concentrations of about 3 °C. Taking into account all other factors as ice sheet and vegetation albedo feedback, the GW can rise up to 4–6 °C (Previdi et al. 2013). Cooling Ocean surface in the North Atlantic with the simultaneously warming Southern Ocean surface (Hansen 2016) provides the increase in the atmosphere kinetic energy, and that can drive more powerful storms. On the Hansen (2016) expertise, the 2 °C global warming above the pre-industrial level is highly dangerous, and he discussed a possibility to stabilize the Earth climate in the case of GHG emission reduction (Hansen et al. 2013a).

Max Planck Institute for Chemistry (MPIC) in Germany provides a research on long-term meteorological datasets and climate modeling for socioeconomic and population projections.

The MPIC research takes into account the dust storms in the Middle East, North Africa, and Eastern Mediterranean area and their influence on the increasing heat extremes (Lelieveld et al. 2014) together with hot weather conditions (Lelieveld et al. 2012). These effect the regional budgets of aerosols and air quality (Pozzer et al. 2012 a, b). Based on the global mortality model (Lelieveld 2013) the estimation of regional and megacity premature mortality due to the air pollution sources was done by Lelieveld et al. (2015). The MPIC climate model predicts the 4 °C global warming above the pre-industrial level, by the middle of this century and rising the maximum temperature during the hottest days up to 50 °C (Lelieveld et al. 2016). So this can happen two times faster and two times higher than it was planned (2 °C) by COP21 in Paris 2015.

In the present time, the global average temperature (mean global surface air temperature—GSAT) exceeds by 0.8 °C (EEA Report No 12/2012) the temperature that prevailed in the era before the industrial development. The WMO underlines that 2015 was the one of the highest on record warm year, and the global average temperature is estimated to have risen by 0.85 °C (WMO 2016a). In the WMO Statement on the Status of Global Climate in 2015 (WMO 2016b), it was estimated as the warmest year on record by far, 0.76 °C above 1961–1990 average and approximately 1 °C increase above pre-industrial era (1850–1900 average) halfway to 2 °C. The North countries are exposed by higher rate of mean surface air temperature rise. For the Russian Federation, the rate of global warming is 2.5 times higher then average over the planet. So for Russia, the 2015 was the warmest on record (2.16 °C) year in comparison with the average temperature in the period of 1961–1990 (WMO 2016b).

On the NOAA (August 21, 2015) image below (Fig. 1), the huge part of the Arctic Ocean has a sea surface temperature anomaly up to +8 °C; at the same time, the north part of Atlantic and Pacific Oceans has a surface temperature anomaly of +11.9 °C. This is a fine example of the effect of Polar Amplification (Masson-Delmotte and Schulz 2013, Box 5.1, pp. 396–398) and illustrates the high positive sensitivity of Greenland ice sheet to increase of greenhouse gases concentration and the global average temperature. From Fig. 1, we can see that the North Polar area in times is more sensitive to GW than the Equator belt.

Furthermore, one can observe a rise of the sea level at the World level (Folger 2013). Global warming, greenhouse effect and human activity are associated with Sea-level rise (SLR). Climate change and associated with Global warming Sea-level rise in the nearest future would be the most important risk factors in the World. They could cause to the wars for vital recourses, mass migration, huge human (Jerrett 2015) and economic losses. Sea-level rise have two main components: ocean thermal expansion and ice melt. The beginning of Global warming associated with increasing of World Ocean heat content and thermosteric sea-level change (Levitus et al. 2012). At the same time, the GW affects the ice caps and produces meltwater.

From Table 1 (Church et al. 2001), we can see that the biggest content of ice deposits is in Antarctic ice sheet (25.71×10^6 km^3) and Greenland ice sheet (2.85×10^6 km^3) and all other glaciers and ice caps (GIC) contain comparatively small volume of ice 0.18×10^6 km^3. The Sea-level rise equivalent can be estimated assuming an Ocean area of 3.62×10^8 km^2. So if all ice on the Earth will melt, the ice sheets of Antarctica and Greenland will contribute 61.1 and 7.2 m to SLR, and all other glaciers and ice caps can increase the Sea level about half a meter. The total SLR in the ice-free World can be 68.8 m. This figure does not contain the SLR from Ocean thermal expansion (Levitus et al. 2012).

In the present time, the glaciers and ice caps are increasing their contribution in SLR (Hock et al. 2009). The previous research of Meier et al. (2007) study the accelerated over the past decade ice loss contribution (60%) from glaciers and ice caps rather than from the Antarctic ice sheet (AIS) and Greenland ice sheet (GIS). But the ice deposit in GIC can quickly melt, and the main source for SLR in the nearest future can be the Greenland ice sheet. The data of Antarctic ice sheet mass balance is not completed yet and has different estimations from mass loss (Church et al. 2013) to gaining mass by NASA (2015).

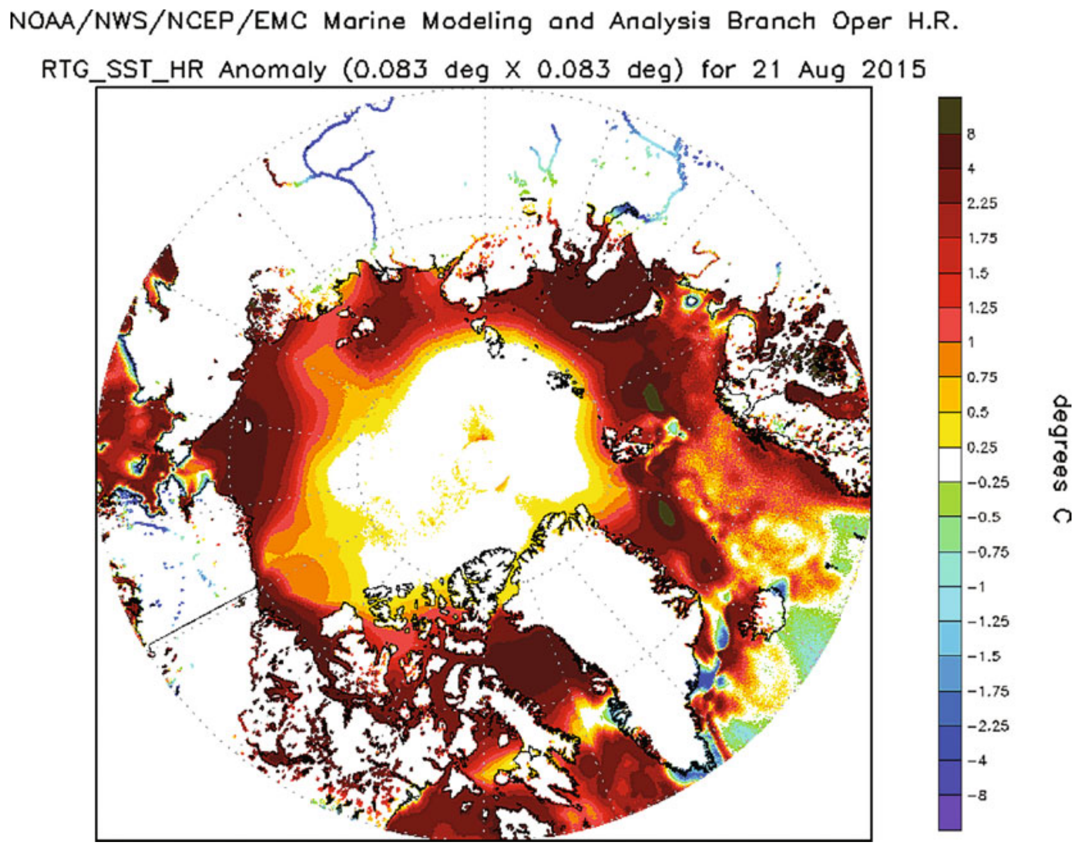

Fig. 1 Arctic Ocean surface temperature anomaly on August 21, 2015. *Source* NOAA NWS NCEP EMC marine modeling and analysis branch, Oper H.R.

Table 1 Some physical characteristics of ice on Earth

	Glaciers	Ice caps	Glaciers and ice caps	Greenland ice sheet	Antarctic ice sheet
Number	>160,000	70			
Area (10^6 km^2)	0.43	0.24	0.68	1.71	12.37
Volume (10^6 km^3)	0.08	0.10	0.18 ± 0.04	2.85	25.71
Sea-level rise equivalent	0.24	0.27	0.50 ± 0.10	7.2	61.1

Source Changes in sea level. Climate change 2001: The scientific basis. Page 648, Table 3 (Church et al. 2001)

The Rate of Antarctic and Greenland Ice Mass Loss

The ocean thermal expansion could not have a significant change in the SLR in comparison with total ice deposit, so mountain glaciers and IC could add to SLR 0.5 m, together with GIS—7.2 m and AIS—61.1 m. In the nearest future, the Greenland ice sheet will the main source of meltwater for the SLR. And the last source will be the Antarctic ice sheet accumulating main reserves of freshwater. On the basis of NASA's GRACE satellites Land Ice monthly data (NASA 2016), we make an estimation of the Antarctica (Fig. 2) and Greenland (Fig. 3) ice mass loss rate.

Antarctica 5-year ice mass loss rate was calculated on the basis of one-year moving average based on the NASA's GRACE satellites Land Ice Antarctica monthly data (NASA 2016). The huge oscillations (Fig. 2) from 6 to 1.8 times are observed in the Antarctica ice mass loss rate. In the August 2015, one can see the 2.03 times faster ice mass loss from Antarctica ice sheet in comparison with August 2010. The oscillation of ice mass loss rate about 3–4 years period (Fig. 2) can slower the ice mass loss rate on the short-time interval and make an illusion of gaining mass (NASA 2015). We can see the polynomial tendency (Fig. 2) of Antarctica ice sheet mass loss with the rate of 1.14 per year at the beginning of 2016 and producing 223.1 Gt of meltwater per year that will contribute 0.615 mm SLR in 2016.

Greenland ice mass loss is going with the faster rate. One-year moving average (Fig. 3) calculated on the basis of the NASA's GRACE satellites Land Ice Greenland monthly data (NASA 2016). Greenland 5-year ice mass loss rate (Fig. 3) was calculated on the basis of one-year moving average estimation. From Fig. 3, we can see that the Greenland 5-year ice mass loss rate has a tendency to slow down but it has 1.74 times faster ice mass loss in August 2015 in comparison with August 2010. We can see the polynomial tendency (Fig. 3) of Greenland ice sheet mass loss with the rate of 1.1 per year at the beginning of 2016 and producing 366.8 Gt of meltwater per year that will be equal to 1.012 mm of SLR in 2016.

The huge variations in Antarctica and Greenland of ice mass loss rate can be a function of the heat transfer in the World Ocean between Equator and Polar areas. The El Nino 2015–2016 maximum has slow down the Gulfstream that will slower the heat transfer to the Greenland ice sheet. Proportionally to this, ice mass loss rate was going with lower acceleration. But in the nearest future, the El Nino event will be overcome and the heat transfer to the Polar areas will

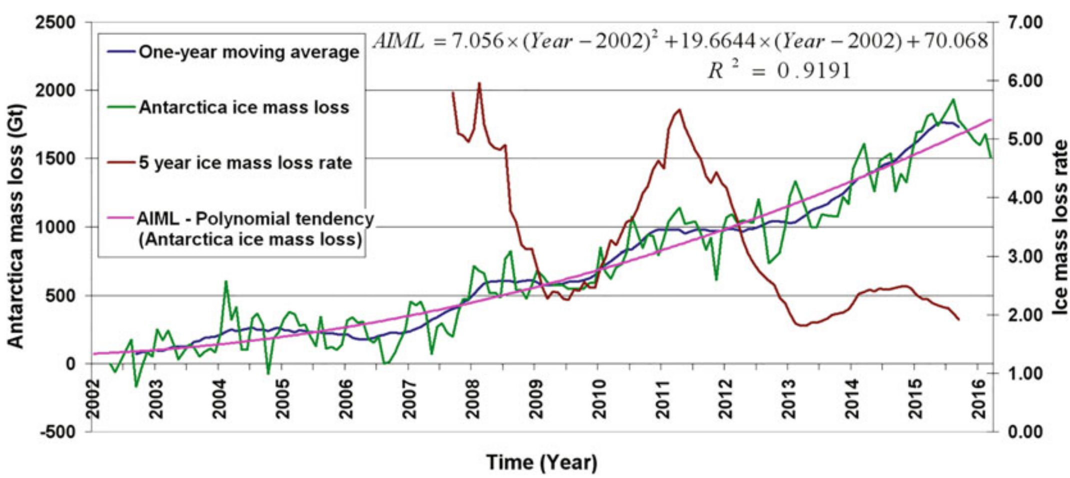

Fig. 2 Antarctica ice mass loss rate. *Source* Authors' calculations based on NASA's GRACE satellites Land Ice monthly data (NASA 2016)

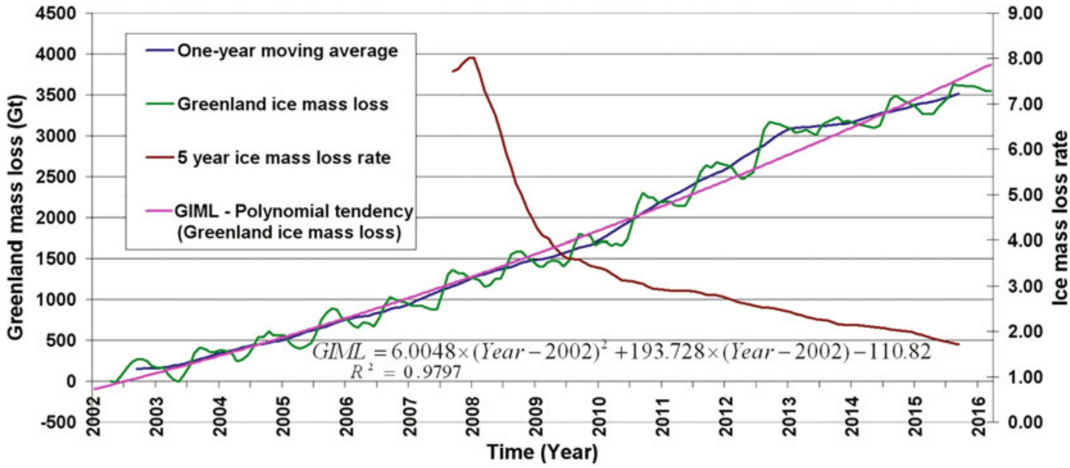

Fig. 3 Greenland ice mass loss rate. *Source* Authors' calculations based on NASA's GRACE satellites Land Ice monthly data (NASA 2016)

increase, so the ice sheet mass loss can accelerate two.

We can conclude that the total Antarctica and Greenland ice mass loss in 2016 can be estimated (polynomial tendency Figs. 2 and 3) as total 589.9 Gt that will contribute the 1.628 mm of SLR. Taking into account the accelerated over the past decade ice loss contribution (60%) from glaciers and ice caps (Meier et al. 2007), we can estimate in the present time the total rate of SLR close to 2 times per 5 years. Due to the slow down of the Greenland ice mass loss rate, we can accept the Hansen (2007) projection on the nearest future that SLR continues to double every 10 years. The COP21 (UNFCCC COP21 2015) solution to adopt the +2 °C increase of the global average temperature and MPIC climate model prediction for +4 °C global warming above the pre-industrial level, by the middle of this century, can lead to unpredictable consequences and can accelerate the SLR in times! But this will be possible to estimate only by fact!

If this threat is real, we can estimate from very simple thermodynamic example. The cumulative energy inflow from 1971 to 2010 into Earth system was estimated to be 790 (with uncertainty value from 105 to 1370) ZJ (1 ZJ = 10^{21} J), relative to the reference period 1860–1879 (Church et al. 2013, Box 13.2, p. 1160). At the same time, the Ocean heat uptake of energy is about 90% (Kuhlbrodt and Gregory 2012). The CMIP5 models predict the proportional thermosteric SLR on 0.11 ± 0.01 m per 10^{24} J Ocean heat content increase (Kuhlbrodt and Gregory 2012). The simple thermodynamics estimation of the energy needed for melting the all ice on the Earth gives us the values: 8×10^{24} J for Antarctica ice sheet; 8.9×10^{23} J for Greenland ice sheet; 5.6×10^{22} J for all glaciers and IC. It looks like that Ocean heat content is comparable with the 9.4×10^{23} J equivalent of the energy capable to melt the Greenland ice sheet and all glaciers and IC. The CMIP5 models demonstrate the energy excess for thermosteric component of SLR twice more the required value. The research of Levitus et al. (2012) estimated in the period of 1955–2010 the World Ocean heat content for the 0–2000 m layer increased by $24.0 \pm 1.9 \times 10^{22}$ J. So the Levitus et al. (2012) estimation is four times less. But in general, these two estimations are the upper and lower boundaries for the 7.7 m SLR (Table 1) due to the melt ice volume equivalent of Greenland ice sheet and all glaciers and IC. If the Global warming gets to the level of +2 or +4 °C, this will happen inevitably by the simple thermodynamic relaxation process due to the huge energy deposit in the World Ocean.

Methods

If the Sea level is rising up in our time, this can happen many times during the past climate records. Only in the Pleistocene period, there was about 30 periods of SLR in the range of −125 to 9.8 m, and in seven cases, the Sea level was higher than at present time. So we can refer to the paleoclimate data to find the relation between the global average temperature on the Earth and future SLR.

Our concept is based on a simple and intuitive method for determining the boundaries of sustainable working of the systems, the variations of their parameters and finding the stationary solutions. We can define the parameters for the future of Earth's climate model and Sea-level rise with the help of the paleoclimate data in the Pleistocene period (from 16 kyr BP to 1.8 Myr BP) (Zachos et al. 2006, 2008; Hansen et al. 2013b). In the previous research (Sorokin and Mondello 2013a, b), we get the stationary solution of future changes in global mean sea level (GMSL) for long-term change in mean global surface air temperature (GSAT) of the Earth. It is clear that the step in the mean GSAT will lead to the change of GMSL in the nearest future. We provide the estimation of the relaxation process with the help of the model based on logistic equation (Sorokin 2015). Due to the fact that the fast oscillations of greenhouse gases (GHG) are going ahead of changes in the mean global surface air temperature, we focus on the more stable paleoclimate GSAT reconstruction. Based on the strong relation between the global average temperature and future SLR (Sorokin and Mondello 2013a, b), we can estimate the costal line change, flooded area, infrastructure and economic losses. The important for decision and policy makers time scale cover short and medium time intervals, but the Climate change and the rate of SLR are going too fast that will affect the World infrastructure and Humanity in this century. To fit these requirements, it is possible to estimate the future Sea-level change from logistic equation (Sorokin 2015). So it is possible to set the time limits for taking a decisions and choice the most effective disaster risk reduction (DRR) strategy in the nearest future.

A Semiempirical Approach

Hansen (2007) proposed to use an exponential growth model that considers the global sea level that doubles in 10 years. This design is consistent with the forecast that the level will rise to a 5 m level in 2100. In some cases, simplified models demonstrate their highly predictive value. Hence, a semiempirical approach proposed by Rahmstorf (2007) showed good concordance with the observed 50 years of ocean level. But this approach does not answer on two questions: How long it will be and where is the upper limit?

Logistic Equation Model for Future SLR

The definition of the global mean sea stationary state level (SL_{St}) that responds to a fixed change of the mean global surface air temperature (Ts_t) must conform to the below main characteristics. Then, to reach a stationary state solution, Earth's climate system needs a sufficiently large relaxation time (Sorokin 2015) and (Sorokin and Mondello 2013a, b, 2015) up to a few hundred years. The present applied approach gives an estimate of the upper bound of the sea-level rise due to changes in the fixed global average temperature in the long run. The boundaries definition for a stationary state of the climate system induced by the fixed change of meteorological parameters allows verifying this hypothesis.

In Sorokin and Mondello (2013a), the following Eqs. (1) and (2) associate both future stationary Sea level (SL_{St}) and GSAT (Ts_t) on Earth:

$$SL_{St} = 7.5 \times Ts_t - 106.875 \ (SL > 0) \quad (1)$$

$$SL_{St} = 24.793 \times Ts_t - 353.306 \ (SL < 0) \quad (2)$$

The assessment of the global average temperature in pre-industrial era $(\mathrm{Ts}_{\mathrm{SL}=0})$ for ($\mathrm{SL}_{\mathrm{St}}$ = 0) follows from Eqs. (1) and (2):

$$\mathrm{Ts}_{\mathrm{SL}=0} = 14.25\,^{\circ}\mathrm{C}; \qquad (3)$$

The GSAT corresponds to the current Sea level $\mathrm{SL}_{t=0} = 0.21\,\mathrm{m}$:

$$\mathrm{Ts}_{\mathrm{SL}=0.21} = 14.278\,^{\circ}\mathrm{C}; \qquad (4)$$

Then, the GSAT in the present time (t = 0) expresses as:

$$\mathrm{Ts}_{t=0} = \mathrm{Ts}_{\mathrm{SL}=0} + 0.8 = 15.05\,^{\circ}\mathrm{C}. \qquad (5)$$

Comparing with the era before the industrial development ($\mathrm{SL}_{\mathrm{St}}$ = 0) in terms of the present time (t = 0), we get the following current climate conditions concerning the global mean sea level (GMSL) rise:

$$\mathrm{SL}_{t=0} = 0.21\ \mathrm{m}; \qquad (6)$$

due to the Global warming and the GSAT exceeds by

$$\Delta T = \mathrm{Ts}_{t=0} - \mathrm{Ts}_{\mathrm{SL}=0} = 0.8\,^{\circ}\mathrm{C}. \qquad (7)$$

Consequently, from Eqs. (1) and (5), an increase of GSAT of 0.8 °C corresponds to a 6-m stationary Sea level. Furthermore, from Eqs. (1) and (4), it is clear that in the aim at preventing any Sea-level rise and maintaining it on the current level (6), the GSAT compared with the era before the industrial development should be reduced by 28.5 times

$$\Delta T = \mathrm{Ts}_{\mathrm{SL}=0.21} - \mathrm{Ts}_{\mathrm{SL}=0} = 0.028\ ^{\circ}\mathrm{C} \qquad (8)$$

and is equal to $\mathrm{LE}_{(\Delta T=0.028,\,t)} = \mathrm{SL}_{t=0} = \mathrm{const} = 0.21\ \mathrm{m}$.

For the transient modeling of the Sea-level (GMSL) growth in response to the global average temperature jump, it is reasonable to apply the saturation model, which can be formalized using the logistic equation (Sorokin 2015):

$$\mathrm{LE}_{(T,t)} = \frac{\mathrm{SL}_{\mathrm{St}} * \mathrm{SL}_{t=0} * (1+\Delta T)^{(t * m_{(\Delta T)}/k)}}{\mathrm{SL}_{t=0} * (1+\Delta T)^{(t * m_{(\Delta T)}/k)} + \mathrm{SL}_{\mathrm{St}} - \mathrm{SL}_{t=0}} \qquad (9)$$

The logistic Eq. (9) should meet the following requirements:

- t—timescale (t = 0 corresponding to the present time);
- Equation (9) for the present time $t = 0$ is equal to $\mathrm{LE}_{t=0} = \mathrm{SL}_{t=0} = 0.21$ m;
- Equation (9) at a value $\Delta T = \mathrm{Ts}_{\mathrm{SL}=0.21} - \mathrm{Ts}_{\mathrm{SL}=0} = 0.028\,^{\circ}\mathrm{C}$ is equal to $\mathrm{LE}_{(\Delta T=0.028,\,t)} = \mathrm{SL}_{t=0} = \mathrm{const} = 0.21$ m;
- Equation (9) at a value $\Delta T = 0$, $a = (1 + \Delta T) = 1$, consequently $\mathrm{LE}_{(T,t)} = \mathrm{SL}_{t=0} =$ const;
- The coefficient $m_{(\Delta T)}/k$ defines the relaxation time for the transient function;
- Considering the condition (6), the coefficients tuning $a = (1 + \Delta T)$, $m_{(\Delta T)}/k$ should initially provide an exponential growth model (9) up to the present time. This one considers that the global sea level doubles every 10 years (Hansen 2007);
- At a value $t \to -\infty$, Eq. (9) tends to zero, $\mathrm{LE}_{(\Delta T>0,\,t\to-\infty)} = 0$;
- At a value $t \to +\infty$, Eq. (9) reaches the stationary level (1), $\mathrm{LE}_{(\Delta T>0,\,t\to+\infty)} = \mathrm{SL}_{\mathrm{St}}$.

For the current climate conditions, we estimate the future sea-level change, using the logistic Eq. (9) with parameters (1), (5), (6), and (7) and coefficients m = 1, k = 100/9.

Figure 4 illustrates the future Sea-level model based on the logistic Eq. (9), and we consider two significant cases. The first one shows the current climate conditions. This one corresponds to a +0.8 °C Global warming above the pre-industrial

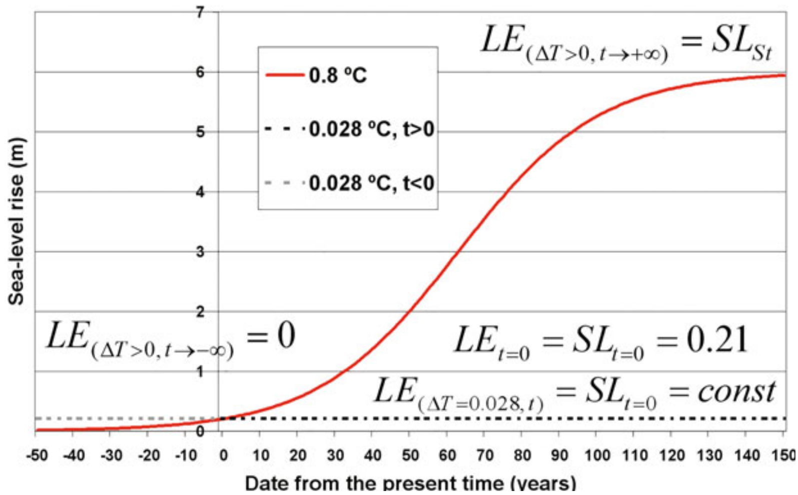

Fig. 4 Future sea-level rise model based on logistic equation for the current value of +0.8 °C global average temperature. *Source* Authors' calculations based on logistic equation model (Sorokin 2015)

level (7). The second one starts from the Eq. (8) where the temperature is +0.028 °C which is 28.5 times less than the first one.

How fast such catastrophic changes in the Earth's climate can occur? If Hansen (2007) is right and if the rise of sea level continues to double every 10 years, then it seems reasonable expecting that the sea level will rise to a +5 m level in 2100 compared to the pre-industrial era level. Figure 4 shows that maintaining global warming at the current value of +0.8 °C for 95 years will increase the sea level to +5 m level. This value fits well with Hansen's prognosis (Hansen 2007; Hansen et al. 2008, 2012). Furthermore, during a 150-year relaxation time, it will reach +6 m stationary solution (Fig. 4).

If Global warming could be possible to reduce of 28.5 times Eq. (8) to the value of +0.028 °C, the sea level would stabilize to +0.21 m which is represented by the black dotted line for $t > 0$, on Fig. 4. The gray dotted line for $t < 0$ (Fig. 4) is only virtual because time does not reverse. The above optimistic scenario is not realistic because the EU Strategy on Adaptation to Climate Change and COP21 aimed at stabilizing to Global warming +2 °C (UNFCCC COP21 2015).

If Global warming reaches the higher values, then we dispose of three possible scenarios for Sea-level rise: the relaxation time does not change; it will happen faster, or it will take more time. To answer this question, we need new data on Global warming and Sea-level rise. The logistic model can calculate the SLR for the temperature step and does not consider the continuous growth of global average temperature. Taking into account the thermodynamics laws, we can consider that the increasing of ΔT will add to proportional increase of SLR. Taking into account the effect of Polar Amplification (Masson-Delmotte and Schulz 2013, Box 5.1, pp. 396–398), we can see that the Polar average temperature will increase in times faster than the global average temperature on the whole planet. So the effect of Polar Amplification can accelerate the SLR. But the huge amount of meltwater can slow down the Ocean conveyor that will reduce the ice melt and SLR. The last two examples can compensate each other, and we can come to conclusion that the relaxation time will not change too much with the global average temperature increase.

According to logistic Eq. (9) and maintaining Global warming at the current value of +0.8 °C (Fig. 4, red line), we can reach the point +1 m SLR in 32 years from the present time. If this will happen three times faster, the decision and policy makers will need to change a working model. The adaptation policy could not be effective after +1 m SLR due to triple reduction of the infrastructure lifetime and huge cost increase in adaptation measures. But the most dangerous is the Global warming. Approximately in this time, the global average temperature can rise from +1.5 to +4 °C. So we need to investigate four cases more to define the future stationary Sea level four different GW scenarios, Eq. (1).

In the case if pursuing efforts to limit the temperature increase to +1.5 °C or reducing emissions to 40 Gt (UNFCCC COP21 2015) will be successful, the SLR will get to +11.25 m. Then, if Earth's global average temperature increases to +2 °C (UNFCCC COP21 2015) above the pre-industrial era, this will lead to an inevitable rise of the global sea level by +15 m according to our model (Sorokin and Mondello 2013a, b, 2015). The UN Conference on Climate Change in Paris (UNFCCC COP21 2015) mentioned a realistic level of the global average temperature to well below 3 °C above pre-industrial level by reducing emissions of GHG by all negotiated countries that will lead to Sea-level rise by +22.5 m. Taking into an account the Max Planck Institute for Chemistry (MPIC) climate model based on dust emission in atmosphere with +4 °C Global warming up to 2050 year, we can predict the very fast Sea-level rise up to 30 m.

The Effect of Global Warming on World Ocean Expansion

We can see the future geographical changes in the coming Global warming World with the help of relation of the global average temperature increase with the future stationary Sea-level values, based on the stationary solution (Sorokin and Mondello 2013a). The Sea-level rise up to 30 m can dramatically affect large areas of Europe. The most significant damage from Ocean expansion threatens: the Netherlands, Germany, Belgium, Dania, Italy, and France. The Netherlands will be completely flooded together with a half of Denmark territory. German coastline will be flooded with the most of communications, plants, industrial areas, seaports, and airport infrastructure. Brussels will be happen on the seashore, and one-fourth part of Belgium will be under the water. Due to SLR, seashore of France (French Riviera) will be strongly changed due to the flooding of the River Rhone Delta. The huge territory of Italy (Venezia) could be flooded that will completely destroy Venezia, Padova, Ferrara, Ravenna, Portogruaro with all railway and road connections. The costal line of Portugal will be affected by the Atlantic Ocean, and huge territory of Lisbon could be flooded. Coimbra, situated deep in the continent, will get a direct connection with the Ocean. So the costal line of whole Europe will be dramatically changed within this century.

In the front of World Ocean expansion, the highly developed countries do not realize the magnitude of this threat. Returning back to the EU's adaptation strategy to climate change of 2 °C, in the nearest future, this will add to +15 m SLR, and consequently, this involves the flooding of 172 airports (19.9%), a reduction of 20.4% in passenger traffic and cargo by 14.7% (Sorokin and Mondello 2015). In the case of MPIC climate model projection with +4 °C Global warming up to 2050 year, we can predict the +30 m Sea-level rise and this can lead to a loss of 247 airports (28.6%) in the EU, reducing by 31.2% of flights and 31.1% in passenger traffic together with reducing the amount of cargo and mail by 25.5% (Sorokin and Mondello 2015; Table 3). The aviation network is closely connected with other infrastructure as towns, roads, rail connections, and industry. So we can expect the similar losses in the whole EU infrastructure.

This World Ocean expansion is also very sensitive to the China, India, Pakistan, Bangladesh, Myanmar, Egypt, Iraq, Iran, and Kuwait. To demonstrate the flooding of these territories, we create an Authors' color modified image of Global Sea Level Rise Map (2016) based on Google Maps. We combine in one map seven layers for SLR and layers with political map, legend, and additional information on GW and future SLR. So from the Figs. 5, 6, 7, 8, 9, and 10, one can see the coastline change map due to the Global warming from 0.03 to 4 ºC equal to future Sea-level rise from 0.2 to 30 m. It is difficult to define the timescale of flooding these territories, but we can create a strong visual link

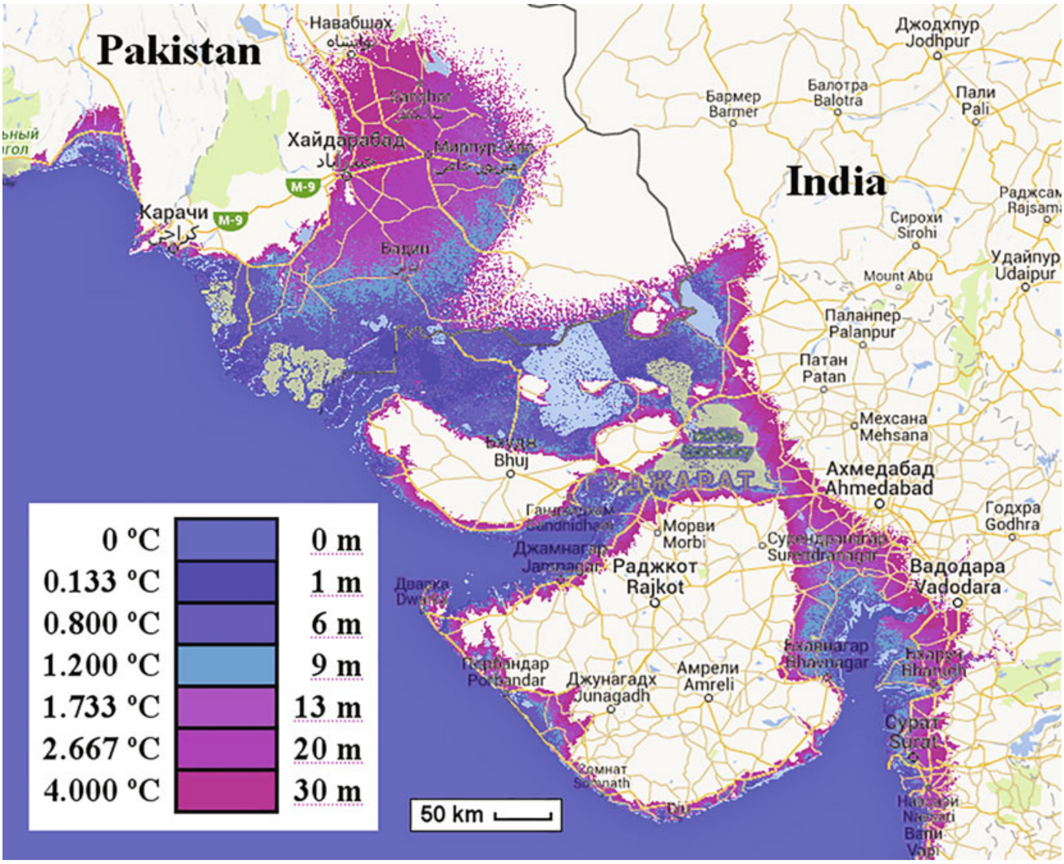

Fig. 5 +30 m future Sea-level rise map of India (Gujarat) and Pakistan. *Source* Authors' color modified image of Global Sea Level Rise Map (2016)

between the global average temperature increase and future Sea-level rise.

The sea-level rise can dramatically affect large areas of India (Figs. 5 and 6). The most significant damage from Ocean expansion threatens States: Gujarat; West Bengal (Kolkata); Orissa; Andhra Pradesh; Tamil Nadu, and Kerala. The SLR can strongly affect the neighboring of India countries as Pakistan, Bangladesh, Myanmar, and China. The huge territory of Pakistan can be flooded close to State Gujarat (Fig. 5). One of the most populated areas of Indian State West Bengal with the capital Kolkata will be flooded by half (Fig. 6). The neighbor Bangladesh will be completely flooded (Fig. 6). The costal line of Sri Lanka will be strongly changed. The Indian Ocean expansion on Myanmar seashore (Fig. 7) can completely flood the capital Yangon and the close towns: Mawlamyaing, Thaton, Pegu, Hinthada, Thandwe, and many small ones.

The common problem for the Indian Ocean region is the huge territory with low elevation above sea level. The GW about +1.2 °C can add to the future SLR up to +9 m, and that will lead to the half of the territory lost in comparison with +30 m SLR. The global average temperature increase to +1.2 °C can happen in the next few years and is significantly lower than 2 °C GW adopted in Paris (UNFCCC COP21 2015). So in this case, the lost of this huge territory with towns and infrastructure will be an inevitable. All this can cause migration in India and huge flows of refugees. Due to the longtime political problems with these countries, the destabilization in these areas will be very difficult for India.

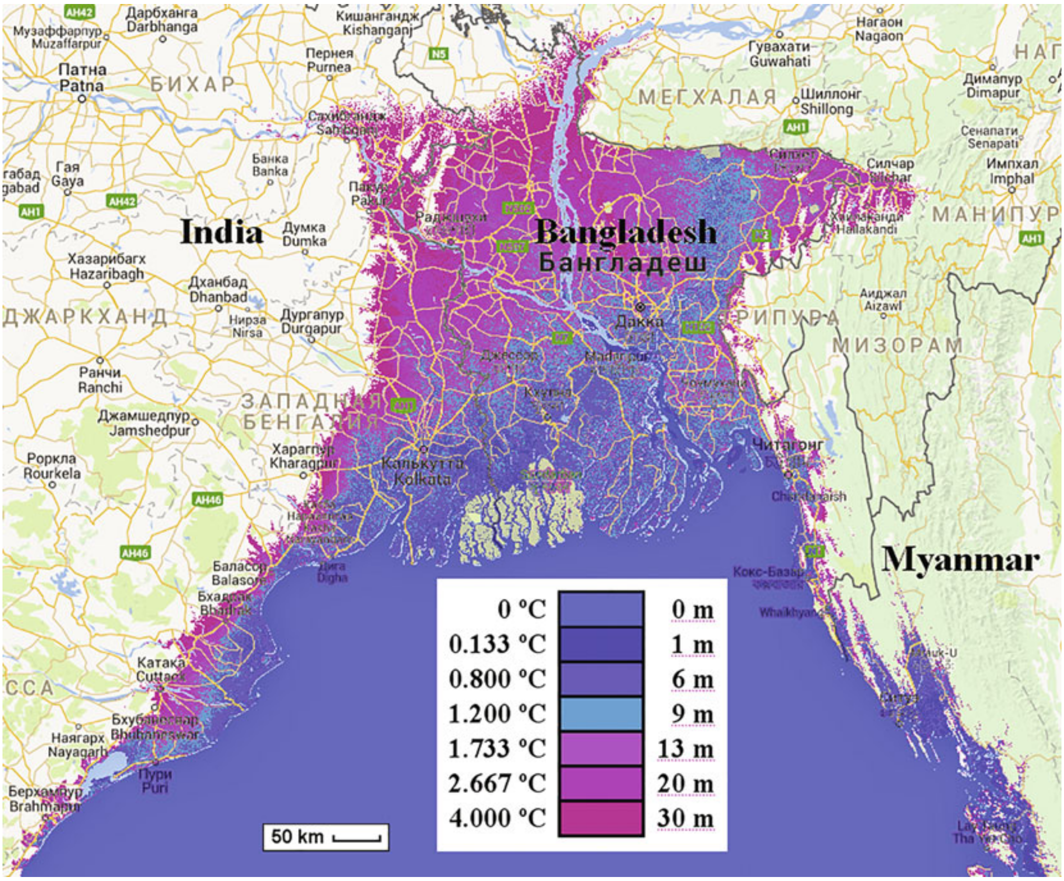

Fig. 6 +30 m future Sea-level rise map of India and Bangladesh. *Source* Authors' color modified image of Global Sea Level Rise Map (2016)

The huge territory of Iraq can be flooded close to Iran border. The Iraq will suffer very much due to the SLR (Fig. 8), and the Persian Gulf will last up to Al Kut and An Najaf. The flooded area is one of the most oil-rich regions of the Persian Gulf, and the lost of this territory can strike the economy of Kuwait, Iraq, and Iran. In the flooded area, it will be possible to build offshore platforms for extracting of oil but it will significantly increase the cost of oil production.

The sea-level rise can dramatically affect large areas of Egypt (Fig. 9), and the Nile Delta can be completely flooded up to Cairo. From the Fig. 9, one can see that the most of the territory can be flooded due to 6 m SLR equal to the current rate of global average temperature increase to 0.8 ℃. So this will be an inevitable SLR. The Cairo can be happen under the Sea level in the case of +4 ℃ GW.

The China is also threatened by the Ocean expansion (Fig. 10). The Yellow Sea coast has a slight elevation above sea level and is the most populated area of China. On the Fig. 10, one can see that the huge cities in China as Beijing, Shenyang, Nanjing, Shanghai, Hangzhou, and Wuhan will be flooded with the future SLR up to +30 m. In the case of China the proportion remains the same an inevitable future SLR up to +9 m will lead to the half of the territory lost in comparison with

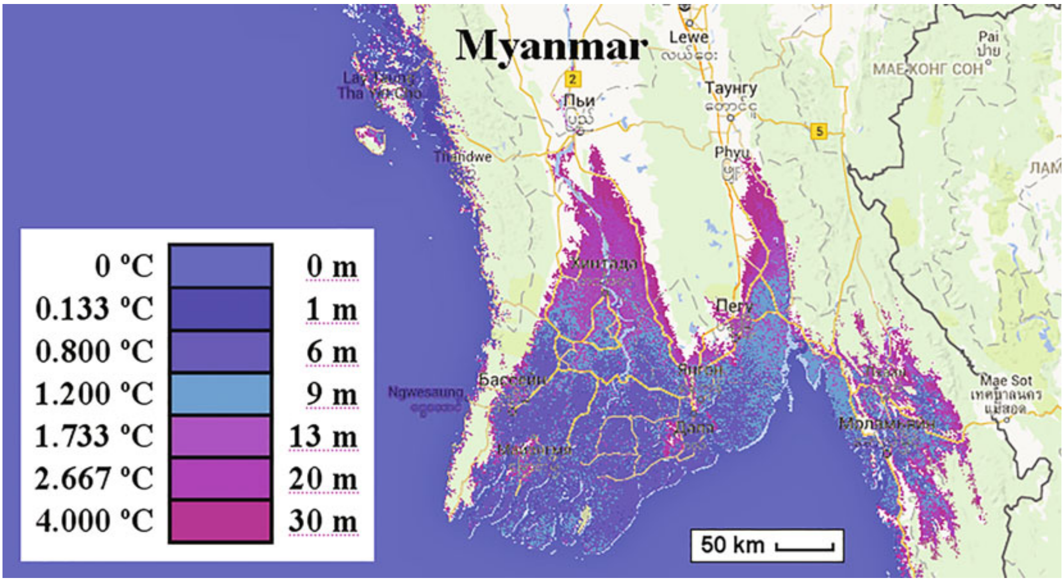

Fig. 7 +30 m future Sea-level rise map of Myanmar flooding territory. *Source* Authors' color modified image of Global Sea Level Rise Map (2016)

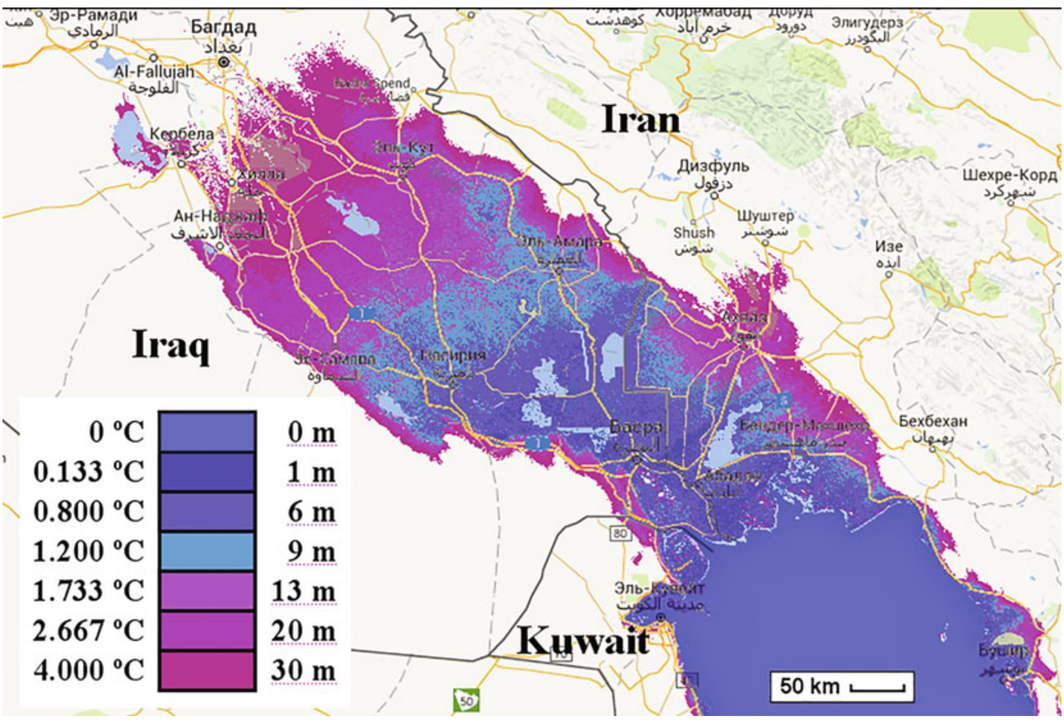

Fig. 8 +30 m future Sea-level rise map of the Middle East flooding territory. *Source* Authors' color modified image of Global Sea Level Rise Map (2016)

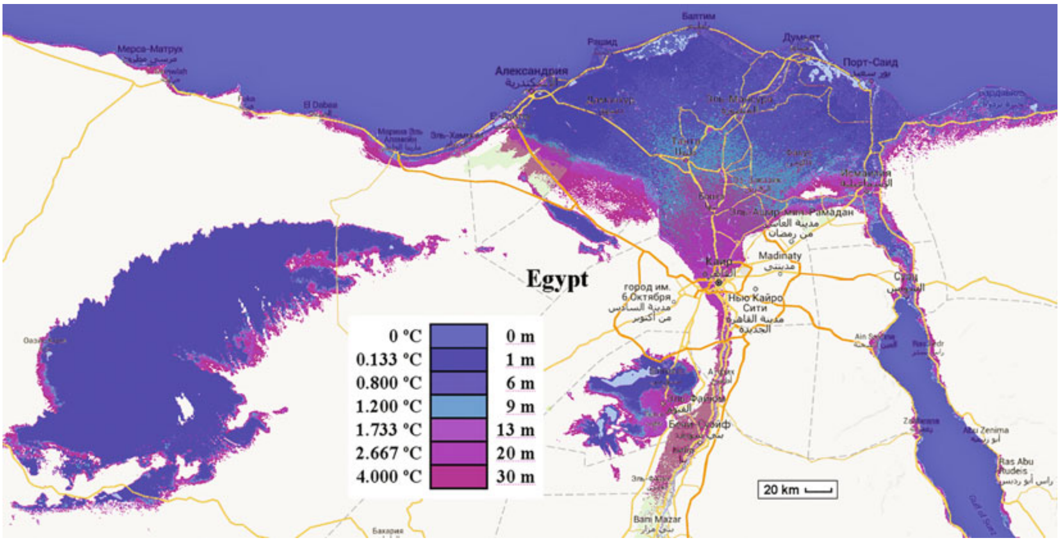

Fig. 9 +30 m future Sea-level rise map of Egypt (Nile). *Source* Authors' color modified image of Global Sea Level Rise Map (2016)

+30 m SLR. The economic losses of China due to the GW and future SLR can be extremely large that can stop the world economic development. We can conclude that for the current level of global average temperature +0.8 ºC above pre-industrial level and further increase to +2 ºC (UNFCCC COP21 2015) and +4 ºC (MPIC) in this century can cause the an inevitable SLR from 6 m up to 30 m in the nearest future. The timescale of these events will depend on future GW value and can go with faster rate.

Results

The EU Strategy on Adaptation to Climate Change does not consider the possibility of a sea-level rise in the upper level +1 m. In the near future, this restriction could lead to catastrophic economic losses.

Taking into an account the COP21 climate change strategy (UNFCCC COP21 2015), we consider (Sorokin and Mondello 2015) five significant cases:

- For the current climate conditions (corresponds to a 0.8 °C Global warming above the pre-industrial level), the model based on logistic equation (with rise rate doubling in 10 years) provides a solution according which, within the next 95 years, the sea level will rise up to +5 m and stabilize at +6 m level within a 150-year relaxation time.
- If global warming could be reduced of 28.5 times to the value of global average temperature 0.028 °C, the sea level would stabilize to the current value of 0.21 m.
- If the global average temperature will increase to 1.5 °C above the pre-industrial era, this will lead to an inevitable rise of the global sea level by +11.25 m.
- If Earth's global average temperature increases up to 2 °C above the pre-industrial era, this will accelerate the sea-level rise up to +15 m in the nearest future.
- A realistic level of the global average temperature increase to 3 °C will lead to Sea-level rise by +22.5 m.

This can happen from 100 years up to 250 years and can be associated with carbon dioxide emission and methane blowout from the Ocean.

We introduce the critical level of global average temperature +1.30(6) °C exceeding which the Earth climate system will be destabilized. This value is 1.53 times less than the +2 °C

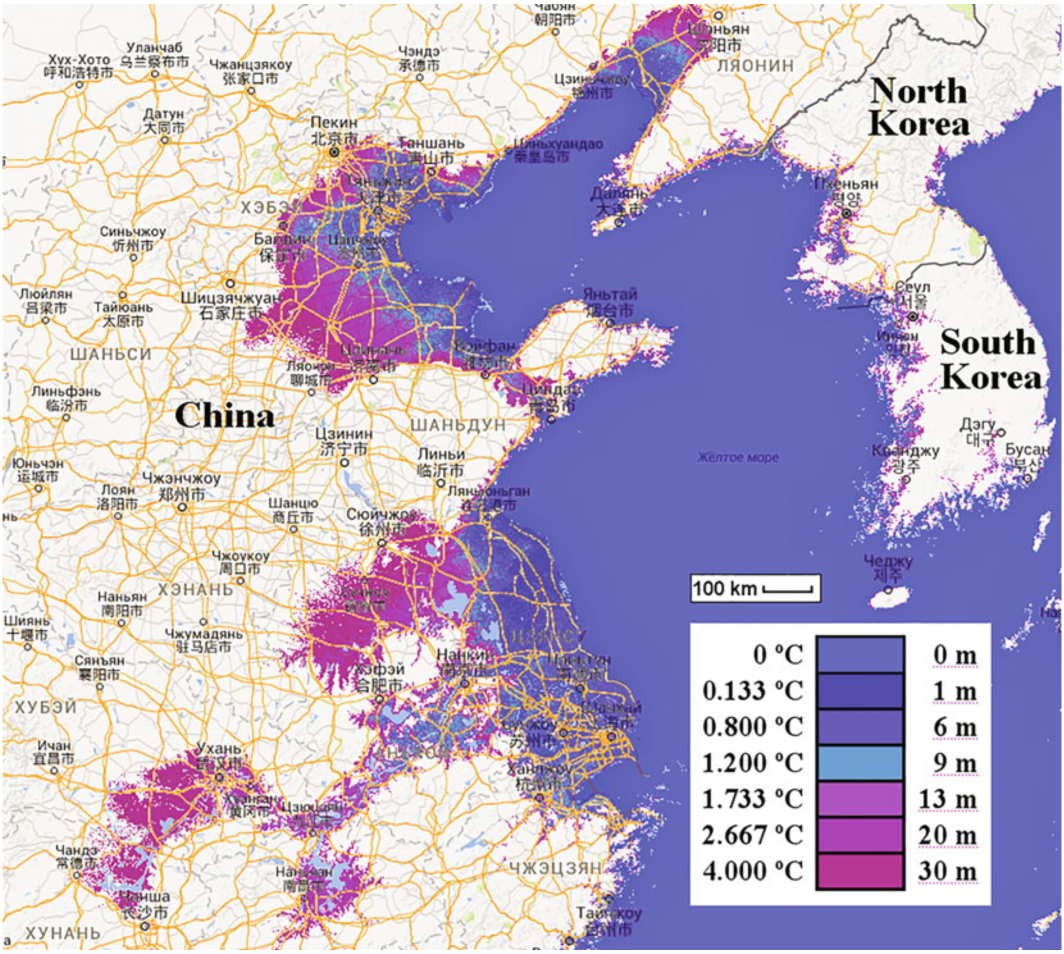

Fig. 10 +30 m future Sea-level rise map of China. *Source* Authors' color modified image of Global Sea Level Rise Map (2016)

GW level adopted in Paris (UNFCCC COP21 2015) as acceptable for sustainable economic development. Exceeding the +1.30(6) °C Global warming or the +9.8 m the Sea-level rise could provoke falling in the next Ice Age. Antarctica ice mass loss and Greenland ice mass loss are going with the rate of 2.03 and 1.74, within five-year period (August, 2010–2015) and estimated as total 589.9 Gt in 2016 that will contribute SLR the 1.628 mm per year.

The most unexpected for decision makers' MPIC result is 4 °C Global warming above the pre-industrial level, by the middle of this century. So this can happen two times faster and two times higher than it was planned (2 °C) by COP21 in Paris (UNFCCC COP21 2015). Taking into an account the Max Planck Institute for Chemistry climate model based on dust emission in atmosphere with +4 °C Global warming up to 2050 year, we can predict the very fast Sea-level rise up to 30 m.

The new infrastructure should be adopted both for +4 °C higher global average temperatures as for the extreme low temperatures of the future glacial period. For economic losses reduction, it is important to avoid building a new infrastructure on the levels below +30 m of future SLR. World Ocean expansion associated with Global warming could cause flooding the most populated and industrial regions that can terminate the sustainable economic development all over the World. The main question is can the national mid-century strategies for the transition to low-emission economies (UNFCCC COP21 2015) stop the sea-level rise before it will be too late.

Discussion

The global average temperature estimated in the warmest on record 2015 year has risen by 0,85 °C (WMO 2016a) and has a tendency for increasing in future. Climatic conditions similar to the currently observed occurred during the Pleistocene: 124, 327, 405, 952 thousand years before present time (kyr BP); 1.07 and 1.23 million years before present time (Myr BP). At the times indicated the ocean level was slightly above the pre-industrial sea level (PISL = 0).

We can underline the Global warming event MIS 5e happened from ~129 to 116 thousand years before present time. In the paleoclimate analysis, Dutton et al. (2015b) show that during MIS 5e, the climate conditions were very similar to the present time: The global average temperature increase was close to ~1 °C of Global warming (Otto-Bliesner et al. 2013); Greenland temperature anomaly was above pre-industrial level from ~5 to 8 °C (CAPE 2006; NEEM 2013); and Antarctic temperatures were warmer from ~3 to 5 °C (Jouzel et al. 2007). The SLR response on Global warming in MIS 5e was estimated in the range of ~6 to 9 m above present (Kopp et al. 2009; Dutton and Lambeck 2012) and was variable in the different parts of the Ocean: GIA-corrected coastal records in the Seychelles were 7.6 ± 1.7 m (Dutton et al. 2015a) and in Western Australia close to 9 m (O'Leary et al. 2013).

We can make a verification of our logistic model with the help of MIS 5e period. The global average temperature increase +1 °C corresponds to the SLR stationary solution +7.5 m that is confirmed by Seychelles records 7.6 ± 1.7 m (Dutton et al. 2015a). The MIS 5e sea-level variation in the range of ~6 to 9 m above present (Kopp et al. 2009; Dutton and Lambeck 2012) corresponds to the global average temperature increase from +0.8 to +1.2 °C. Just now, we enter +0.8 °C Global warming. So it can be formulated as a result that during the MIS 5e period, the observed climate conditions were in accordance with our logistic model: Global average temperature increase 1 ± 0.2 °C corresponds to SLR 7.5 ± 1.5 m.

The highest Pleistocene period sea-level rise was 9.8 m above pre-industrial level. We can estimate the global average temperature increase as +1.30(6) °C corresponding to this SLR stationary solution +9.8 m. This historical global warming maximum was terminated by the next Global Ice period, which lasted about 100 thousand years. The global average temperature dropped down on 4.84 °C below the pre-industrial level that provokes the World Ocean level sharp decline on 120 m. The most of the Europe was covered by the ice sheet of a few kilometers thick which lasted until Moscow city (Russian Federation). The North Africa and a part of Sahara desert were covered by ice.

At the present time, the humanity is trying to repeat this scenario and already reproduced the climate parameters as global warming and greenhouse gases concentration of GW historical maximum happened 124 thousand years before present time. It is very important to understand could the global average temperature increase +2 °C lead to Sea-level rise on +15 m? Or the +9.8 m is the critical equilibrium level when trying to exceed it the trigger effect could happen and Ice Age will change Global warming. The fact is that we have no evidence of World Ocean exceeded the level of +9.8 m in past 1.8 million years. So the +2 °C Global Warming could provoke entering the next glacial period.

So it will be wise to consider the Global warming critical level at +1.30(6) °C. This is a point of unstable equilibrium, exceeding the +1.30(6) °C Global warming, or the +9.8 m SLR could provoke falling in the next Ice Age. But it is 1.53 times less than the +2 °C GW level adopted in Paris (UNFCCC COP21 2015) as acceptable for sustainable economic development.

It means that we can fall in the next glacial period faster than reaching the limit to below +2 °C above pre-industrial level and corresponding for it sea-level increase of +15 m (Sorokin and Mondello 2013b, 2015). Global warming and the Sea-level rise will provoke the next glacial period that starts with fast temperature falling down and the 7.5 m sea level declining per 1 °C (Eq. 1) up to "zero" sea level and after that accelerating 3.3 times to 24.79 m per 1 °C (Eq. 2). The new infrastructure should be adopted both for +4 °C higher global average temperatures as for the extreme low temperatures of the future glacial period. For economic losses reduction, it is important to avoid building a new infrastructure on the levels below +30 m of future SLR.

Conclusion

Summarizing the results, we can recommend the immediate measures to slow down the coming climate catastrophe and reduce the economic losses from the climate change. The most effective solutions for disaster risk reduction are the following:

- Zero emission technology;
- Preventing of methane emission from Arctic;
- Preventing of methane emission and blowout from the Oceans;
- Negative emissions (Gasser et al. (2015) and Hansen et al. (2013a)) can be effective instrument for cooling the Earth atmosphere and taking the SLR under control;
- Making efforts for the getting down of the global average temperature to the pre-industrial level.

Thus affords should reduce the number of natural disasters in times and slow down the Sea-level rise.

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Climate Change and Coastal Megacities: Disaster Risk Assessment and Responses in Shanghai City

Ruishan Chen, Yazhou Zhang, Di Xu and Min Liu

Abstract

Climate change has had and will have a great impact on coastal areas. Coastal cities are increasing vulnerable to extreme climate events owing to their growing populations and assets, as well as land use change in the coastal areas. Shanghai, a mega coastal city in East Asia, has frequently affected by tropical cyclones and heavy rainfall. It is among the most vulnerable cities to floods worldwide. However, climate change and urbanization will make the situation even worse. Considering the main risk sources of coastal flooding, we combined scenario analysis, geographic information system (GIS), and hydrological models to examine the impacts of rainstorm waterlogging, typhoon storm surge, river floods, and sea-level rise in Shanghai. Based on a comprehensive review of climate risk factors, we explored the disaster prevention and adaptation measures in Shanghai. Finally, we provide some suggestions on spatial-specific emergency measures to enhance resilience in Shanghai and beyond.

Keywords

Climate change · Flood risk · Shanghai · Resilience building

Introduction

Climate-related disasters are and will be major threats of cities in this century (Hallegatte et al. 2013; Hansen 2010; Hanson et al. 2011; Knutson et al. 2010; Lane et al. 2011; Lin and Emanuel 2016; Lin et al. 2012; Mendelsohn et al. 2012; Min et al. 2011; Mokrech et al. 2008; Muir Wood et al. 2005; Pall et al. 2011) (Fig. 1), especially for coastal cities (Bouwer et al. 2010). Hurricane Sandy, the most destructive hurricane

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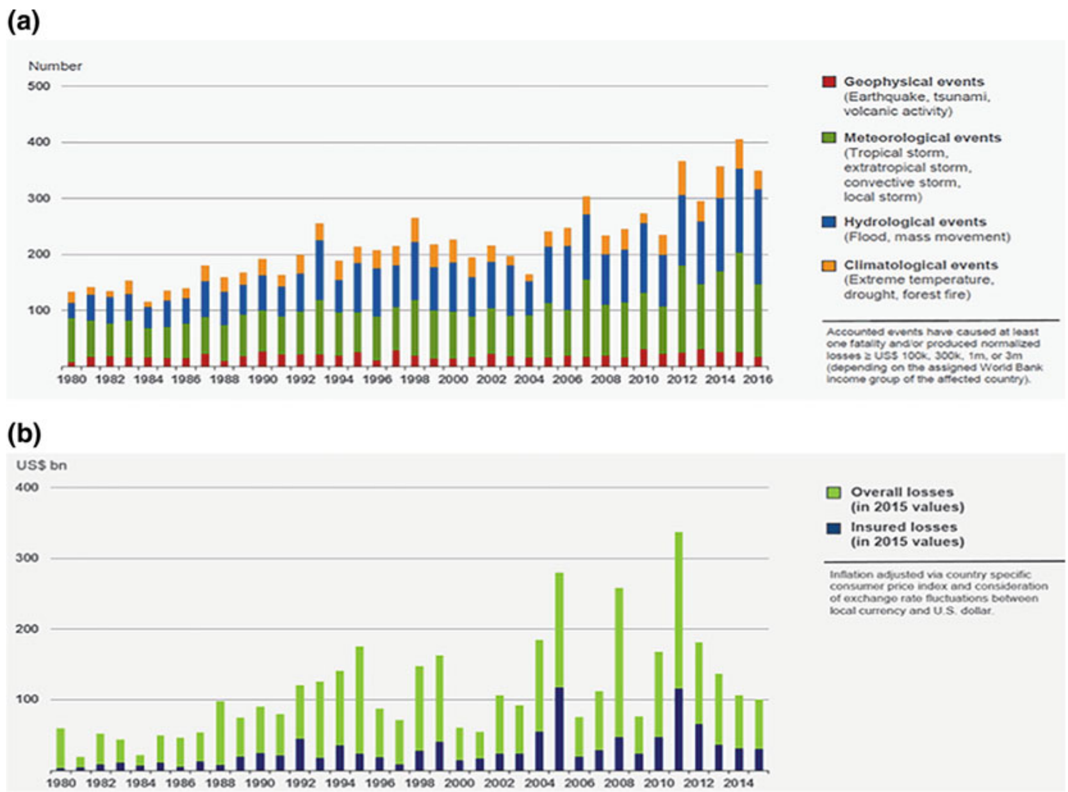

Fig. 1 **a**, **b** Number and losses of natural disaster events from 1980 to 2016 (*source* © 2016 Munich Re, Geo Risks Research, NatCatSERVICE. As of July 2016.)

of 2012, made landfall in New York in late October, nearly 53 people died, thousands of homes and an estimated 250,000 vehicles were destroyed during the disaster in New York, and economic damage reached $19 billion. Power was out to 2.2 million people in New York City for nearly three days. It is the second-costliest hurricane in US history (Rosenzweig and Solecki 2014). Climate change will have major impacts this century even if the countries of the world abide by the national commitments made at COP21 in Paris to reduce greenhouse gas emissions. IPCC AR5 confirmed that global warming is unequivocal, and the last three decades have been successively warmer than any preceding decade since the instrumental record began in the nineteenth century. It is also projected that cumulative emissions of CO_2 will determine global mean surface warming by the late twenty-first century, and most aspects of climate change will persist for many centuries even if emissions of CO_2 are stopped (IPCC 2014). Along with this, global mean sea level and frequency of severe storms will continue to rise during the twenty-first century. Climate-related disasters will be the new normal. This is a great challenge in this century.

Given the high density of populations and built infrastructure, cities are especially vulnerable to climate change, which has brought multiple threats: flood, drought, high-speed winds, heat waves, and diseases (Haines et al. 2006; Watts et al. 2015). News about climate change-related disasters, including rising sea levels and storm surges, extreme downpour, inland, and coastal flooding, is quite common; these disasters have widespread negative impacts on people (and their health, livelihoods, and assets) and on local and national economies and ecosystems. Climate change can greatly affect urban infrastructure systems (energy supply, sanitation and drainage, transport, and telecommunication), services (including health care and emergency services), the built environment, and ecosystem services (water supply). These interact with other social, economic, and environmental stressors which will exacerbate individual and household well-being (Tapsell et al. 2002). These risks are amplified for those who live in coastal cities of low-lying and hazardous areas such as delta region. Coastal cities around the world have tried to address the challenges brought by climate change. New York has formed the New York Panel on Climate Change (NPCC), which periodically assesses the impacts of climate change and identify the suitable strategies to adapt. NPCC has released four reports which assessed the climate change and associated impacts to the city's infrastructure since 2008 (NPCC 2017). UK explored the risks of flooding and coastal erosion over the next 100 years nationally in 2004 and provides the action plan to address these risks (Robson 2002; Wheater and Evans 2009; Wheater 2006). The City of London has published its climate change adaptation strategy in 2011, which aims to manage risks and increase resilience (Nickson et al. 2011). Cities like Paris, Durban, Rio de Janeiro have joined the Urban Climate Change Research Network (UCCRN) and tried to cope with climate-related disasters (UCCRN 2017).

The State Council of China has issued the "guiding opinions on promoting the construction of sponge city" in October of 2015, and then in the March of 2016, the National Development and Reform Commission and the ministry of housing and urban–rural development of China released the action plan for urban adaptation to climate change; these two guidelines recognized the importance to address climate-related issues in cities. However, these policies should be based on assessment of current and future climate trend and explore the potential impacts and adaptation strategies. We will explore the flood risk in Shanghai with climate change and come out of some suggestions to enhance the resilience. The experience gain here can support other estuarine cities to adapt to climate-related disasters.

Overview of the Drivers and Impacts of Coastal Flood Risk

Climate change-induced flood exposure is increasing in coastal cities owing to growing populations and assets, changing land use, sea-level rise, and subsidence (Wang et al. 2012; Woodruff et al. 2013). Delta cities will be particularly vulnerable (Claudia et al. 2012; Mokrech et al. 2008; Palanisamy et al. 2014; Parthasarathy 2009; Peduzzi et al. 2012; Tapsell et al. 2002; Townend and Pethick 2002). Characterized by the interplay between rivers, lands, and oceans and influenced by a combination of river, tidal, and wave processes, deltas are coastal complexes that combine natural systems in diverse habitats and human systems (Sherbinin et al. 2007). As low-lying plains, deltas are subject to climatic impacts from rivers upstream (e.g., freshwater input) and oceans downstream (e.g., sea-level changes, waves, winds) as well as within the deltas themselves (e.g., heavy downpour) (Claudia et al. 2012). Meanwhile, they are affected by human activities such as land use changes, dam construction, irrigation, mining, extraction of subsurface resources, and urbanization (Nicholls et al. 2007). In the past decade or so, coastal cities have experienced huge flood disasters with major economic losses, including heavy rainfall-induced floods in Beijing (July 21, 2012), Hurricane Sandy in New York City (2012), Typhoon Haiyan in the Philippines (2014), and the mega-floods in Bangkok (2011), Typhoon Fitow and heavy floods in Yuyao and Ningbo City in Zhejiang Province of China (2013), India's Chennai floods (2015), and the floods created by prolonged rainfall in Wuhan city of China (2016).

Although there are many reasons of urban flood, its direct drivers are from land use change, climate change, inadequate infrastructure, and other factors which mainly come from inappropriate human actions. The underlying drivers of flood include the demographic change, the socioeconomic development in the cities, the technology and its proper or improper use, the policy and institutional conditions, and cultural factors which affect people's attitude about environment and their perception of risk (Fig. 2). Coastal cities in China are particularly vulnerable to climate-related disasters as coastal areas accommodate more than 25% of the country's population and contribute to more than 55% of the GDP. Coastal zones are also centers of biodiversity, featuring a wide variety of habitats—estuaries, mangroves, sea grasses, and dunes—accommodating important species (Meehl et al. 2005). Shanghai, the financial hub of China as well as global financial center, has always been affected by climate-related disasters (Vance 2012). Located at the river mouth of Yangzi River with an elevation of 3–4 m (one quarter of the area lies below 3 m), Shanghai, is identified as one of the top cities for both population and asset exposure to coastal flooding (Deng and Wang 2015; Nicholls et al. 2007). The storm precipitation of one year has increased from 35.5 to 38.2 mm/h. The rapid increase in the urban population and economic development makes Shanghai even vulnerable to climate-related disasters (Wang et al. 2012). Currently, flood research in Shanghai is fragmented and future flood risks and their potential impacts are underestimated (Fig. 3).

As a global city, the climate-related disasters increased remarkably in Shanghai in recent years, with growing economic losses. It is reported that Shanghai was the most vulnerable city among nine selected biggest coastal cities around the world which facing severe floods (Balica et al. 2012). However, so far, Shanghai has not done any specific assessment on urban climate change and its impact. The public society has experienced many natural disasters, but there is very few capacity building on flood risk awareness. After each disaster, the city lacks of post-disaster assessment and effective impacts

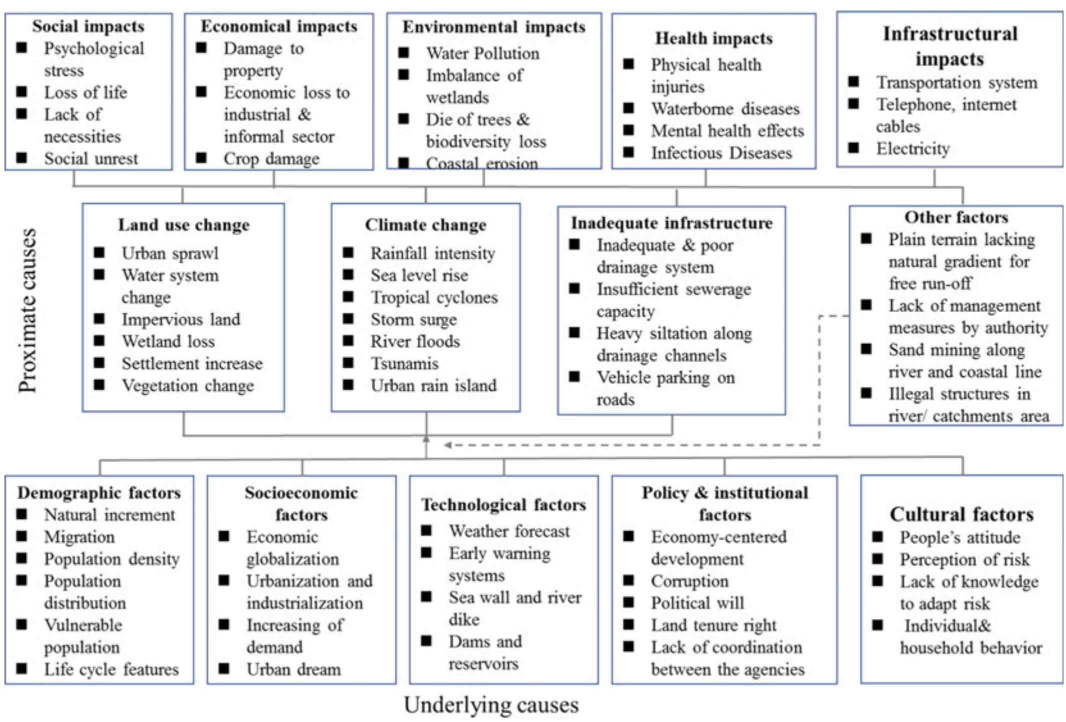

Fig. 2 Drivers and impacts of urban floods in coastal area

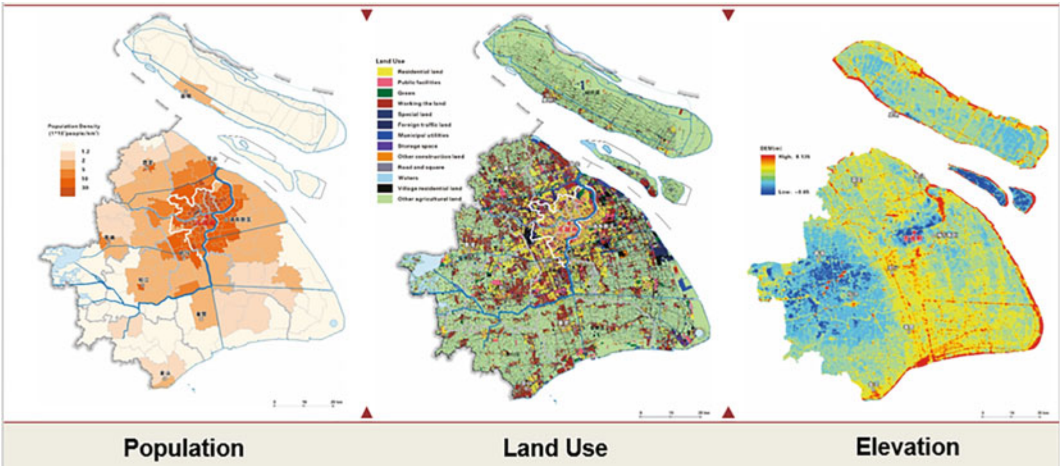

Fig. 3 Drivers of flood risk in Shanghai city

investigation, which has not prepared enough knowledge to deal with future flood risks.

Current Flood Characteristic in Shanghai

Categorizing flood events are essential to explore the future flood risks (Hall et al. 2006). According to the disaster-forming mechanism and regional characteristic of disaster-forming environment, floods can be divided into dam bursting flood, overbank flood, flash flood, rainstorm-induced flood, storm surge-induced flood, and tsunami-induced flood from the perspective of geography (National Disaster Reduction Center of China 2004). The flood disaster in Shanghai can be divided into storm surge-induced flood, rainstorm-induced flood, and overbank flood, and rainstorm-induced flood is the dominate flood disaster (Quan 2014). Shanghai is a low-lying city but has a low standard drainage in some regions; the frequency of rainstorm is high, which can easily result in urban waterlogging. It will submerge the roads and seriously affect the life of the residents and their low-lying houses.

Shanghai is located in the middle of Chinese eastern coastline, north of Yangtze River estuary, and south of Hangzhou Bay, where is a typical mid-latitude transition zone. It has a fragile ecological environment which lacks of natural barrier to withstand storm surge (Wang et al. 2012). The city is low lying, and most of its area is coastal alluvial plain, which has an average elevation of about 4 m (Wusong elevation). Storm surge is one of the main threats to Shanghai urban safety. Tropical cyclones frequently affected Shanghai. The tropical cyclone records show that at least 109 tropical cyclones attacked Shanghai from 1638 to 1911; when a tropical cyclone attacked the inland of Chongming, Hengsha, and Changxin in 1905, these three islands were flooded and no people were left (Deng and Wang 2015). In recent years, the number of storm surges near Shanghai area has an upward trend. Projections of future tropical cyclone probabilities also show Shanghai will be severely affected (Woodruff et al. 2013). Although the intensity of storm surge is weak and less affected in some years, its potential impacts cannot be ignored. However, current research on Shanghai is static and few have looked into the future storm surge dynamics. Large losses from extreme storm surge can only be reduced if substantial researches have done on this subject and also are informed to the decision makers (Fig. 4).

With large number people living within coastal floodplains, and a lot of land and assets

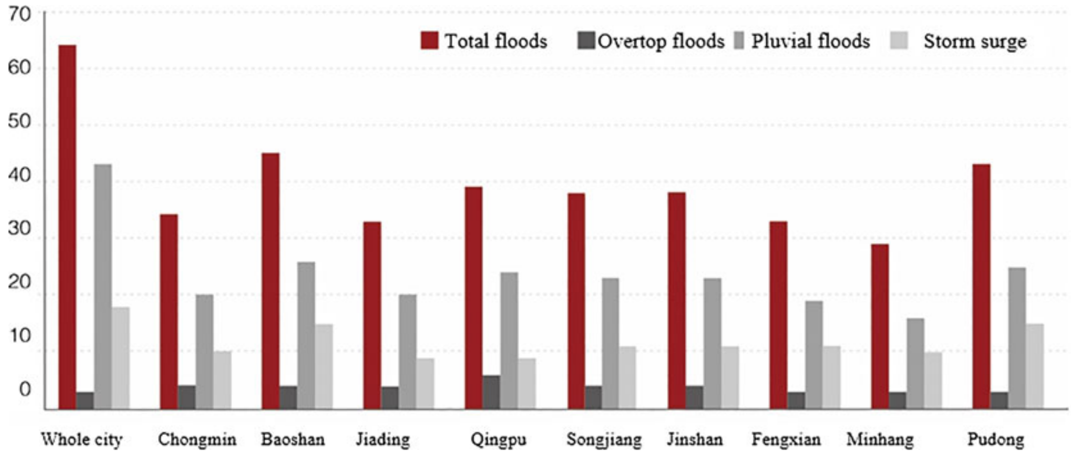

Fig. 4 Flood numbers in districts of Shanghai from 1949 to 2000

lying less than 1 m above current sea level, sea-level rise is one of the major risks associated with global warming. It will directly inundate some low-level areas, but also indirectly increase the intensity of storm surge and flood a large area. IPCC's projections indicate that the sea level will rise 86.6, 185.6, and 433.1 mm by 2030, 2050, and 2100, respectively.

Sea-level rise is an underestimated issue in Shanghai, while some studies have explored the extend of sea-level rise around Shanghai, but its impacts on coastal erosion, water provision, coastal ecosystem and infrastructures, and coupled relations with other factors are less explored. Shanghai is a low-lying area, its storm surge flooding defense totally depend on coastal protection infrastructures. The land subsidence is very high, with around 4 mm/a at some observed stations. And the absolute sea-level rise is almost 2 mm/a at the region. It is estimated that the relative sea level will rise 16 cm by 2030 (Cheng et al. 2015); Shanghai has become one of the cities that will be most severely affected by sea-level rise. Rapid rise in sea level will directly affect the effectiveness of the protection works and urban infrastructure, while producing a variety of hazards, storm surges, floods, coastal erosion, and saltwater intrusion. Besides, wetland ecosystems will suffer great impact, and the estuary and coastal erosion will be intensified. Saltwater intrusion will affect the safety of drinking water which will reduce the days for water provision. But the adaptation strategies of all these issues were not explored.

Besides, compound extreme flood risk from heavy precipitation, storm surge, and future sea-level rise was not explored; great gaps exist on the extent, duration, and intensity of extreme flood disaster for Shanghai area. Modeling the joint impacts of sea-level rise, storm surge, and heavy precipitation with higher temporal and spatial resolution is very critical for sustainable development in Shanghai.

Flood Risk and Its Spatial Distribution in Shanghai

To further enhance the safety level of Shanghai city, an in-depth assessment of the flood risk should be performed within and around Shanghai city, to inform the decision making on disaster prevention and mitigation in Shanghai's 2040 urban planning. A flood hazard analysis has been conducted to identify the occurrence probability and magnitude (i.e., inundation depth, flow velocity or discharge, duration) of the potential flood within a specified period of time and over a given area (Yin et al. 2013, 2015, 2016). Associated with the drivers of flood hazards, a series of modeling tools are available to examine the flood risk in different time scales with different foci, such as MIKE21, FloodMap, and HAZUS-MH Flood Model (Figs. 5 and 6).

Rainstorm Waterlogging

Formulate scientific and rational planning of comprehensive urban disaster prevention requires a detailed understanding of waterlogged points under extreme precipitation in Shanghai. Urban rainstorm waterlogging was explored in GIS environment at different scenarios to identify the risk level in Shanghai city. Overall, the rainstorm waterlogging risk differs greatly in Shanghai, and the rainstorm waterlogging risk in city center is higher than the suburbs, so city center should be the primary target of risk management and control.

Based on the data on land use, drainage system, and digital elevation model (DEM) of Shanghai in 2006, with the support of storm waterlogging model (SUWM), we simulate the water depth owing to return period of 20 years, 50 years, 100 years, 500 years, 1000 years floods, respectively, in the ArcGIS environment. Then, we get waterlogged point profiles of Shanghai under different extreme precipitation scenarios.

The results show that, under extreme precipitation scenario, Shanghai waterlogged points

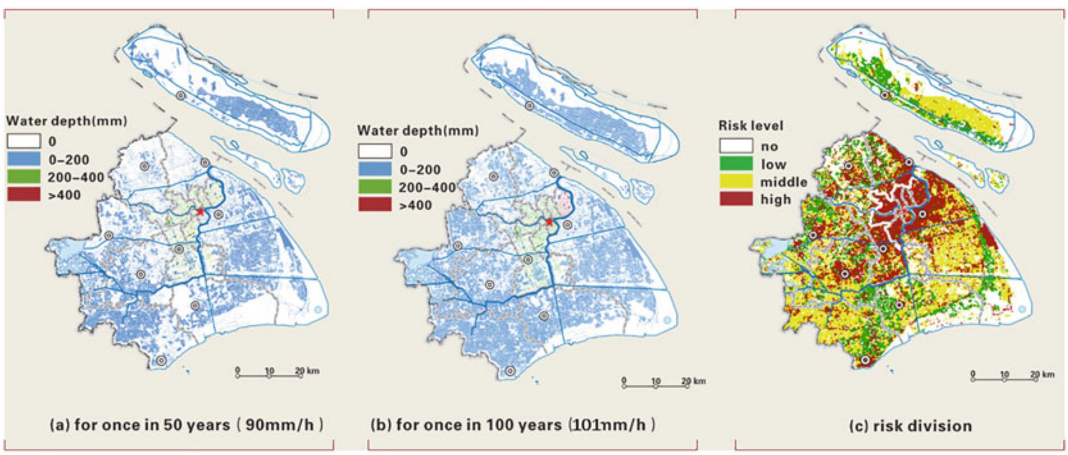

Fig. 5 Rainstorm waterlogging simulation under different scenarios

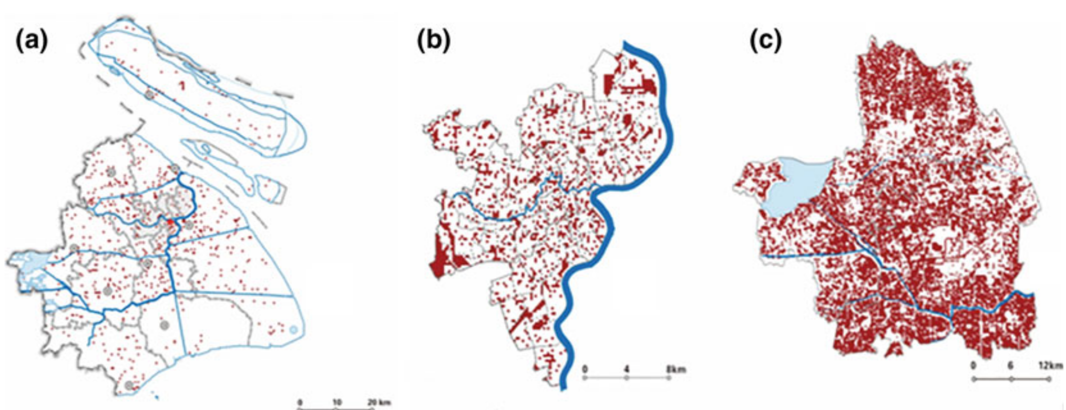

Fig. 6 Vulnerable waterlogging point in Shanghai (**a** whole city area, **b** central urban area, **c** upper watershed area of Huangpu River)

mainly are distributed in roads, the city center, and suburbs; rainstorm waterlogging risk is higher in the central city than the suburbs, so the city center is a priority area in Shanghai rainstorm risk mitigation. In the context of rapid urbanization, Shanghai has low-capacity drainage system, shrinking river and lake system, low vegetation coverage, and rising impervious surface area (Grum et al. 2006). These are the major causes of waterlogging points formation.

Considering the main causes for the formation of floods, from a land use perspective, we suggest policies and actions should pay attention to the following areas in terms of risk prevention:

1. "Re-naturalization" of downtown area: increasing green roofs, permeable pavements, and green road belts to alleviate the production of rainfall flow from inner city waterlogging; reconstructing drainage systems and establishing some artificial water systems, such as ground/underground storage tank, recovering lakes and river networks to reduce drainage pressure to rivers and pipe networks; retrofitting some of low-lying lands to multifunctional parklands, and increasing the capacity of floods storage;
2. "Ecological conservation" of suburb area: constructing additional wetlands and woodlands to reduce surface runoff; keeping and protecting a substantial amount of water areas, dredging and repairing key rivers regularly to ensure storage capacity of floods; designing multifunctional park lots scientifically to increase flood diversion regions;
3. Upgrading waterlogging standards: upgrade the standard for discharging in the urban area to once in 50 to 100 years (key rivers for once in a century); the downtown and suburban urbanization clusters (especially upstream areas of Huangpu River) for once in 30 to 50 years; other regions of suburban areas for once in 10 to 30 years.

Typhoon and Storm Surges

We categorize the typhoon which will affect Shanghai into three types, the landing on northern Zhejiang path, the direct landing on Shanghai, and the northern offshore landing path. By applying the Danish DHI MIKE 21 hydrodynamic model, with input from the typhoon path, sea-level rise, land subsidence, sea erosion and seawall, and other permutations and combinations in the evolution of the current situation and the target year (2040), a total of 12 kinds of scenarios were explored.

The results show that the flooding caused by northern Zhejiang landing path mainly located in Chongming Island, the area near Wusong and Luchaogang of Shanghai. Storm surge broke some seawall which resulted in flooding. This type of typhoon caused a relatively large impact on Chongming Island. The type of typhoon which directs landing on Shanghai has relatively smaller flooding area than the typhoon which landing from northern Zhejiang; the impacts are mainly located around Chongming Island and the area near Wusong. The third type of typhoon has less impacts than the northern Zhejiang landing path and frontage landing path. Its impacts mainly concentrated in the low lying along the northern Chongming Island (Fig. 7).

Based on the results illustrated above, the maximum possible storm surge inundation depth and scope at the time in 2040 in the Shanghai area can be understood. To address the risk related to storm surge, following adaptation measures should be considered:

1. A barrier should be built in the estuary of Huangpu River, and the flood diversion areas should be opened up the in the low-lying areas near Wusong Estuary.
2. Emergency evacuation sites should be established in some population centers of Chongming Island.

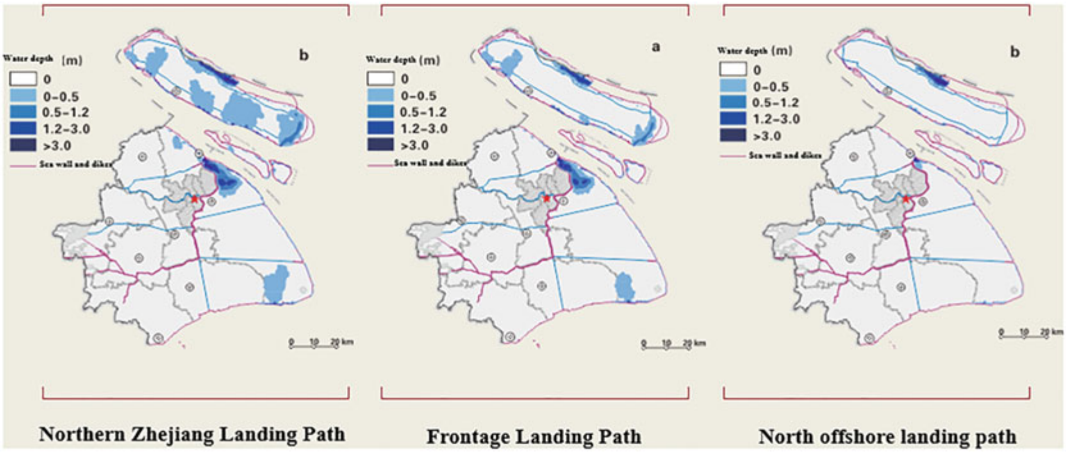

Fig. 7 Distribution of different types of typhoon flooded area

3. Seawalls in southern Chongming Island should be reinforced to ensure stability of coastal areas. The height of seawalls in the north of Chongming Island, especially Xinglongsha area, should be raised to about 0.88–1.31 m by 2040 because of its weakness for preventing storm surge.
4. Considering the land subsidence and sea-level rise, the height of seawalls should be augmented to about 0.61–1.06 m until 2040 at the Huangpu River estuarine of Baoshan District.
5. Due to coastal erosion at the north of Hangzhou Bay, the beach protection measures should be strengthened, especially in frontier parts of seawalls in Luchao Port and Jinshan Petrochemical Factory, and increasing dam capacity along the beach may be necessary.

Huangpu River Storm Tide

Based on the maximum water level data of three major hydrological stations of Wusong Estuary of Huangpu River, Huangpu Park, and Mishidu, the flood frequency distribution was calculated for each site. The storm induced flood frequency—intensity analysis of Huangpu River showed that the existing flood prevention wall design cannot meet the ability to defense flood at the lowest upstream areas. Its lowest wall can only stand once a 50-year tide. In the once-in-500-year and once-in-1000-year scenarios, the whole Huangpu River bank will be flooded. The current design standards of river dike for flood protection are based on the frequency analysis of 1984, despite repeated reinforcement, the actual level of flood protection dike still cannot guarantee to avoid the once a millennium flood event. As the elevation of Huangpu River decreased from downstream to upstream, the scope and depth of inundation from upstream to downstream both decreased.

To address the river floods, the following mitigation measures can make a difference:

1. Some measures should be taken to divert floods at upstream area, such as constructing underground storage facilities, and reutilizing old air defense facilities and underground parking lots.
2. In some midstream and upstream areas, buildings and infrastructures should not be constructed within three kilometers on both sides of the river, especially in the low-lying areas of Minhang and Songjiang districts.
3. A barrier should be built in estuary area of Huangpu River to prevent from seawater inflow too fast to minimize the risk of tidal flooding.
4. Engineering design standards for flood control, the river dike, for instance, should be improved to once in a thousand-year frequency.

Extreme Sea-Level Rise

Relative sea-level rise is mainly caused by the absolute sea-level rise, land subsidence, and tectonic sinking (Arkema et al. 2013; Yin et al. 2009). Based on the digital elevation model, the impacts of sea-level rise showed that the most affected areas are in Chongming Island, Changxing and Hengsha Island which located in the Yangtze River Estuary (Fig. 8).

Applying the DEM, land use, and population density data, the greatest losses caused by flood located in the city center with a 12-km buffer zone. This area has high population density, low lying elevation, and a lot of important economic activities; once submerged, the loss will be very serious. Considering the high risk in this area, following adaptation strategies are recommended:

1. The central city area with a radius of 12 km has the highest flood risk; the coastal line of Shanghai ranges 14 km, it contains the key protected zones which are not suitable for resettling much population and important infrastructure, and the preexisting facilities such as seawalls should be protected. The road which connected Chongming Island to outside should be strengthened in order to evacuate and rescue in an emergency.
2. Three defensive lines should be constituted: The first line of defense is the beach—wetlands—islands which aims to strengthen the protection of the wetlands at East Chongming Island, Jiuduansha, and East Nanhui. The second line is the existing coastal dike which aims to raise the design standards of dikes. The third line is the existed and planned urban wetland park. Trees should be planted between the parks for controlling the floods.
3. The ecological environment of coastal inshore island should be protected, and the beaches and wetland should be maintained. The ecological regulation reservoir in the upper Huangpu River should be constructed. The ground subsidence in coastal areas should strictly control the high-rise buildings.

A Comprehensive Disaster Prevention Framework

Key Strategies of Disaster Mitigation

1. Constructing infrastructure for disaster prevention in Shanghai. As a coastal city, coastal areas of Shanghai frequently affected by natural disasters, such as typhoon, storm surge,

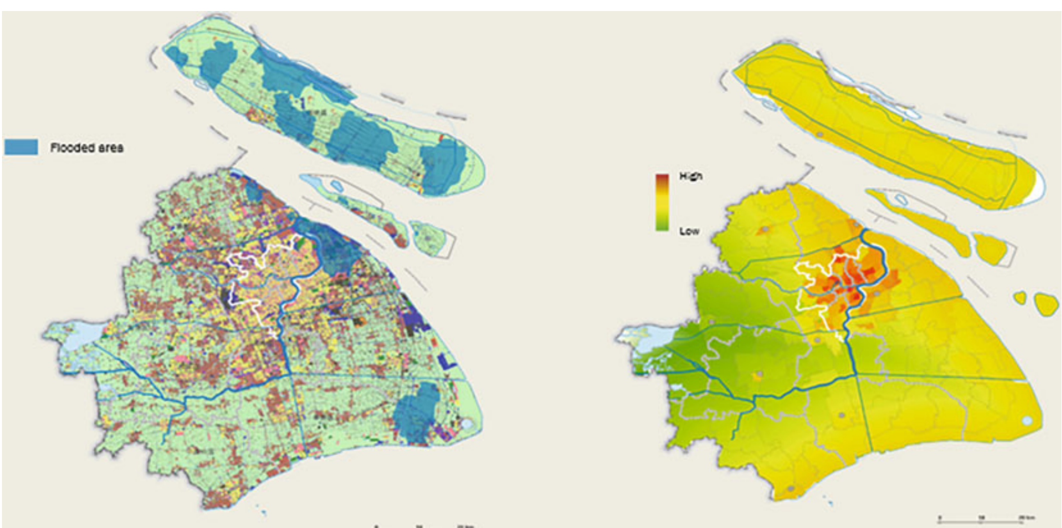

Fig. 8 Most vulnerable area induced by typhoon storm and the flooding in Shanghai

heavy precipitation. In addition, the high density of population and buildings along the Huangpu River, the low-lying flat area, and more serious waterlogging made the city very vulnerable to flood disaster. This becomes a high incidence of urban safety issues. Therefore, the coastal disaster prevention line should be built which comprises the following: protecting wetlands at Yangtze River Estuary islands; the seawall defense system; coastal wetlands or green space system along the coastal line. These defense systems as a whole constitute the coastal disaster prevention framework which can resist strong typhoon winds, storm surges, as well as waterlogging and other disasters. At the same time, there is a need to strengthen the Huangpu River flood control projects and rationally plan of the use of coastal urban space.
2. Strengthen risk planning of waterlogging and other disasters in the city. Shanghai is in the low-lying coastal areas; considering the land subsidence and rising sea levels, the occurrence of typhoons, rainstorms, and other disasters, the city is very sensitive to waterlogging. Identifying risk of natural disasters and frequent anthropogenic disasters and its formation mechanism are the cornerstone of the development and implementation of disaster risk planning. Risk assessment can help urban planning to avoid residents living in areas liable to waterlogging, while the excavation site and routes should be planned in the waterlogged area and more parks and green space system should be created to increase water infiltration.
3. Enhance defense evacuation capabilities. Shanghai, as a modern metropolitan city, was developed vertically which includes the underground space which includes metros, shopping mall and other infrastructures, ground space which include residential houses, roads, commercial, and industrial rooms; and high buildings and overpasses. It is necessary to strengthen the interaction at different layers. In case of emergency, the evacuation should be maximized to make a difference. A resilient system can also save social and economic resources which can support the sustainable development of the city.

Key Stages of Urban Disaster Reduction

1. Establish urban security system as a priority

Urban security system includes disaster mitigation planning, institution framework, legal system, and related resources. To make the system effective, all the elements should work connectively. This involves improving disaster prevention and mitigation plans. The disaster mitigation and emergency plan should be specific in its content. The process of approval, registration, disclosure, evaluation, and revision of disaster mitigation plans should be transparent and legitimate. The emergency plan, departmental resources deployment, disaster response plans, local emergency plans, and large-scale enterprises and agencies' recovery plans should be coordinated systematically and easy implemented. All of these can form a coherent and complete system or a toolkit which can be applied when necessary. Improve disaster response system which includes the organizational management system, early forecast and warning system, emergency platform system, emergency support system, and institutional response resource person. Improve disaster prevention and mitigation mechanisms, which include disaster emergency response mechanism, monitoring and early warning mechanism, information reporting and updating mechanism, integrated rescue mechanism, training mechanism, recovery and reconstruction mechanisms, investigation and assessment mechanism, public communication and mobilization mechanism, regional and international cooperation mechanisms. All of these mechanisms should be coordinated in a graded system which can guarantee that adequate actions should be taken at certain time. Clear responsibilities should be allocated at all levels of administration to strengthen the capability of local government. The stages of urban security planning can be divided into: urban land use planning, urban disaster prevention planning, urban disaster management planning, urban disaster relief, recovery, and reconstruction planning. However, the disaster prevention and mitigation measures should be standardized and improved. From the perspective of the law, normalization and legalization of emergency management can guarantee the successfulness of public emergencies and also recover the normal production and living.

2. Emergency response during disasters

The main actions during the disaster emergency include emergency information dissemination, evacuation, self-help and cooperation, rescue, emergency resources reserve, and deployment. The agencies of emergency response should follow the allocation of responsibilities and the requirements of the emergency plan, dispatch of emergency rescue experts, materials and equipment in time and give feedback to the city emergency response center in time. Considering the importance of communication during a disaster, information dissemination should be timely, accurate, and objective. And the rescue should be comprehensive and efficient.

3. Recovery after the disasters

For the regions which have suffered losses from flood disaster, actions on relief, compensation, resettlement, or reconstruction are necessary to recover to normal life. Besides, to investigate the tangible and intangible loss, carry an assessment of the disaster and report the lessons learn from the disaster is important for resilience building of the city. Currently, this mechanism is lacking in most Chinese cities.

Water Protection

Considering the characteristics of flood in Shanghai, and the density of population and built-up areas in the city, reduction of the flood disaster should focus on the risk of dike breaking, road and underground space waterlogging, low-lying area submerging, house collapse, and injuries from falling object. The main approach took by the city government includes the principles of people oriented, human life safety first, the city chief executive responsible for the urban safety; cooperation between the army and the public society to cope with disaster, and enhance regional cooperation. The city has built 523 km of seawall, 511 km of embankment, the regional inundation control system, and city drainage system to protect the city from flooding. Besides, the city has designed its own organization system; early warning system and emergency plan; information communication system, rescue, and relief system. Water is the basic needs of industry and public service sectors; it is important for social stability and livelihood security. Shanghai government has always taken urban water supply security seriously; it has invested on the construction and protection of water source, centralizing water supply for the suburbs, strict management of underground water, improving water quality, and effectively protect the people's water demand for livelihood.

Conclusions

Extreme climate and weather-related disasters are and will be major threats of cities in this century, especially for coastal cities. Many coastal cities have initiatives on disaster risk reduction and create formal mechanism to contribute to urban resilience building, such as the NPCC mechanism. International organizations also pay great attention to reduce urban disaster and enhance the urban resilience. Shanghai city can gain many experiences from other cities. Based on the vision of strengthening defense capabilities to cope with disasters and improve the urban resilience, we assessed the flooding risk in Shanghai and provide suggestions to address the flooding risk and its negative impacts. To reduce flood risk and enhance the urban safety, systematic approaches should be taken to innovate urban planning and improve the flexibility and adaptability of risk control measures. The sustainable development of the city should have a priority on disaster management and identify the balance of economic, social, and environmental aspect of development.

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La Niña Event 2010–2011: Hydroclimatic Effects and Socioeconomic Impacts in Colombia

Germán Vargas, Yolanda Hernández and José Daniel Pabón

Abstract

During the second half of 2010, the global climate system has been affected by the presence of anomalous cold conditions in the tropical Pacific related to a strong La Niña phenomenon, which continued throughout the first half of 2011, and had a second pulse in the boreal winter of 2011–2012. Climate patterns around the world were affected causing marked anomalies and important socioeconomic impacts in different countries. During this period, Colombia experienced a hydroclimatic anomaly expressed in precipitation levels above normal and extreme events such as flash floods, landslides, and long-term flooding of plains in different regions of the country. Losses and damages to infrastructure, crops, and livelihoods reached more than 7.8 billion US dollars (approximately 2% of 2011 GDP). Due to the flooding of a vast area, about 2,350,000 people were affected, and as consequence most of them were expelled from their territories to live in alien territories in very difficult conditions; in these areas, many social conflicts either arose or worsened. Some of these conflicts are pointed out at the end of this chapter with the aim that they may serve as lessons for strengthening the regional disaster risk management for being better prepared against adverse impacts of similar extreme events in the future.

Keywords

La Niña 2010–2011 · Floods in Colombia

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Introduction

It has been established by several researchers (Kenyon and Hegerl 2010; Stockdale et al. 2010), that the extremes in the interannual climatic variability worldwide are characterized by abnormally warm or cold temperatures on the surface of the tropical Pacific broadly known as El Niño and La Niña phenomena. The climate abnormalities caused by these phenomena have different manifestations in different regions of the planet (Rasmusson and Carpenter 1982; Rasmusson and Wallace 1983; Ropelewski and Halpert 1987; Masson and Goddard 2001; Li et al. 2011) which impact the natural and socioeconomic systems of the countries affected (Glantz 1997; Diaz and Markgraf 2000) by causing large disasters that upset the welfare and the development of communities insofar as macroeconomic indices.

The second half of 2010 saw a cooling of the surface of tropical Pacific, which recorded as a strong La Niña phenomenon (BoM 2012) with a strong first pulse that lasted the full first half of 2011. At the end of the same year, a second pulse was recorded, that maintained the La Niña conditions well into the first half of 2012. The 2010–2011 abnormal situation in the tropical Pacific brought with it heavy rainfall and flooding in Australia (BoM 2012), North America (Rippey 2015), and South America (Arias et al. 2015).

It is broadly known that the tropical Pacific anomalies alter the Colombian climate (Poveda 2004). Mainly, under El Niño conditions, a large portion of the country including the Andean, Caribbean, and North Pacific regions experiences a lack of rainfall, leading to forest fires and droughts (IDEAM-DPAD 2002). In most of La Niña events, these regions withstand abnormally abundant rainfall, with flash floods, long flooding, and landslides in the plains (IDEAM 1998).

The La Niña phenomenon of 2010–2011 brought about a particular climatic anomaly in Colombia, expressed in abnormal rainfall with levels not previously recorded within the available measurement period (the last 50 years) as reported by Euscateguí and Hurtado 2011. This rainfall led to landslides and long-lasting, extensive flooding on plains, which in turn strongly affected the population and its activities. This chapter examines the 2010–2011 event and the impact of long-lasting plain flooding in Colombia, integrating both climatological and socioeconomic aspects which have not previously been addressed by other authors in their descriptions (e.g., IDEAM 2011; CEPAL 2012; Hoyos et al. 2013).

La Niña Event Observed in Second Half of 2010 and First Half of 2011 Years

Figure 1 shows the behavior of the Ocean El Niño Index (ONI) and the sea surface temperature (SST) on different sectors of the tropical Pacific between 2009 and 2013 (the Oceanic Nino Index (ONI) is a three-month running mean of SST anomalies in the Nino 3.4 region (5° N-5S, 120–170°W), based on a base period, currently the 1976–2015 period). In this figure, it is possible to verify that in the second half of 2009 and the first quarter of 2010, the tropical Pacific remained with positive SST anomalies related to the El Niño event 2009–2010 (see Fig. 1a) which finished between March and April of 2010.

A sudden cooling occurred by mid-2010. By July, the SST anomalies registered values below −0.5 °C and achieved the minimum (values below −1.5 °C) between November and December of 2010, when the event reached its greatest intensity (Fig. 1b). These anomalies persisted until April 2011, when this La Niña event finished, lasting 10 months (July 2010—April 2011).

It is worth mentioning that an even faster or more abrupt cooling such as that observed in mid-2010 was observed in June 1998 as a transition from the intense 1997–1998 El Niño to the intense 1998–2000 La Niña. Likewise, it is of note that the 2010–2011 La Niña took place during a negative phase (cooling in the eastern sector of Pacific) of the Pacific Decadal Oscillation (PDO), occurring right at its minimum, which adds to the intensity of the cooling.

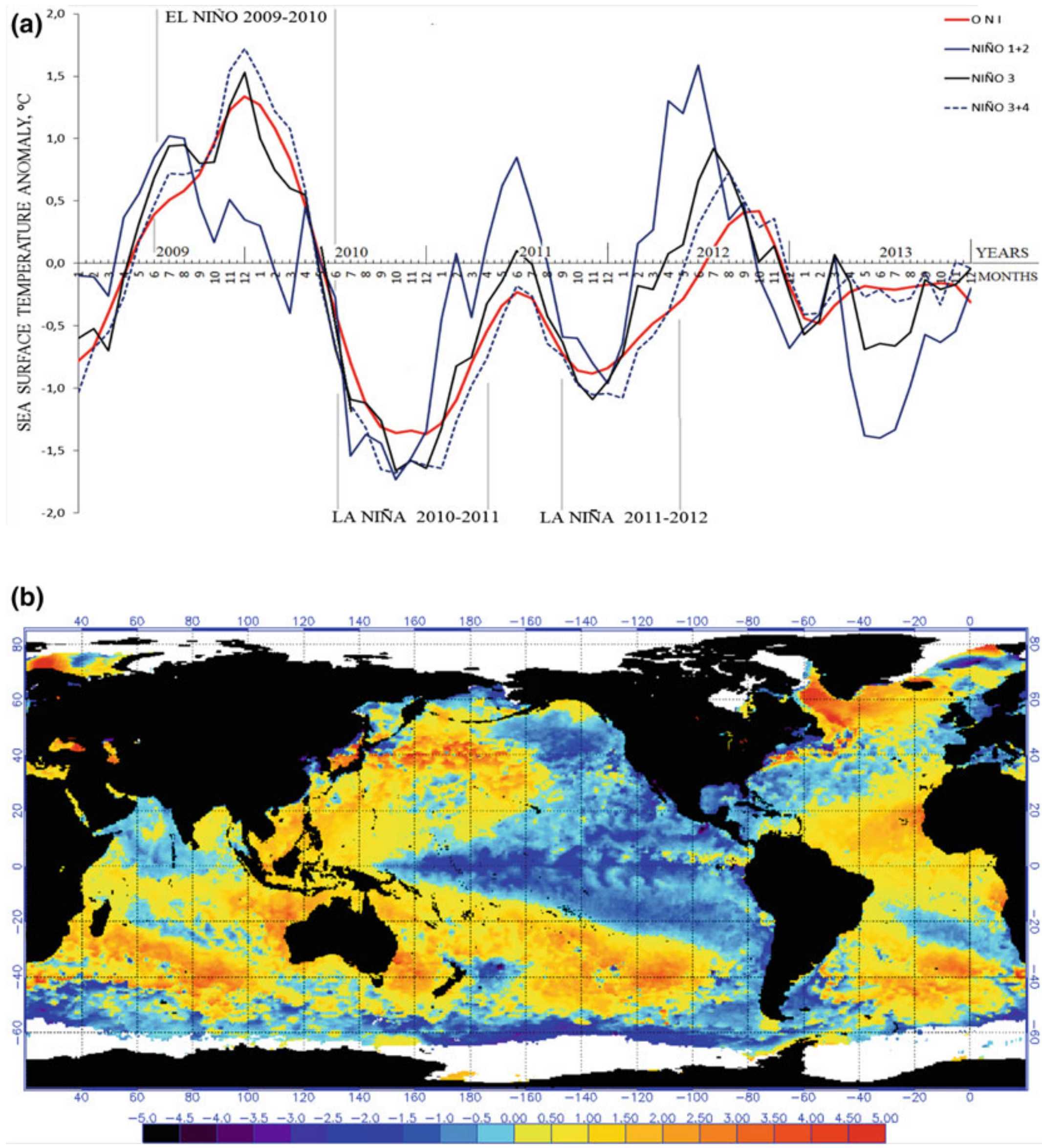

Fig. 1 **a** Behavior of the Ocean El Niño Index (ONI) and of sea surface temperature anomalies on the eastern tropical Pacific (Niño 1 + 2), central tropical Pacific (Niño 3), central-western tropical Pacific (Niño 3.4) and western tropical Pacific (Niño 4) between 2009 and 2013. **b** Distribution of sea surface temperature anomalies in December 2010 according to http://www.ospo.noaa.gov/data/sst/anomaly/2010/. In blue, negative anomalies or sea surface temperature below normal (cooling)

This negative PDO phase extended from the beginning of the 2000 decade and ended approximately in 2014, according to PDO monitoring data published by the Joint Institute for the Study of the Atmosphere and Ocean (JISAO) in the Web page http://research.jisao.washington.edu/pdo/. The magnitude of this negative PDO phase as recorded between 2010 and 2011 was similar to that observed at the beginning of the 1970s.

The La Niña 2010–2011 Event's Climate Effects in Colombia

The 2010–2011 La Niña phenomenon brought with it climatic anomalies to the Colombian territory that manifested themselves with alterations of the patterns of monthly mean air temperature and monthly precipitation (IDEAM 2011). From July 2010 to April 2011, the mean monthly temperatures were below normal levels in large sectors of the Andean and Caribbean regions, particularly in the La Guajira peninsula where monthly air temperature anomalies reached −2.0 °C. Strongest negative temperature anomalies were recorded during July, August, November, and December of 2010, and again in March and April of 2011. Yet the climatic effects of La Niña 2010–2011 on the Colombian territory were especially expressed in rainfall over the different regions. Figure 2 features the spatial distribution of monthly rainfall anomalies in Colombia during 2010 and 2011.

In order to understand the effects of the La Niña phenomenon and other climate variability oscillations on the climate of different regions of Colombia, it is necessary at the beginning to know the annual cycle of precipitation in these regions. In the Andean sector of Colombia, for instance, two rainy seasons are observed: the first in March-April-May, and the second in September-October-November, dry or less rainy months are December-January-February and June-July-August.

The Caribbean region of Colombia has a different pattern in the precipitation seasonality: a dry period from November to April, a period with rains since April still June, a mid-summer dry period (canicula) in July-August, and a rainy season in September-November-December. In the Colombian Pacific, particularly over northern region, there is no dry season, but a period with less precipitation is observed in February-March.

Figure 2 shows that the Andean (specifically the basins of the Cauca and Magdalena rivers)

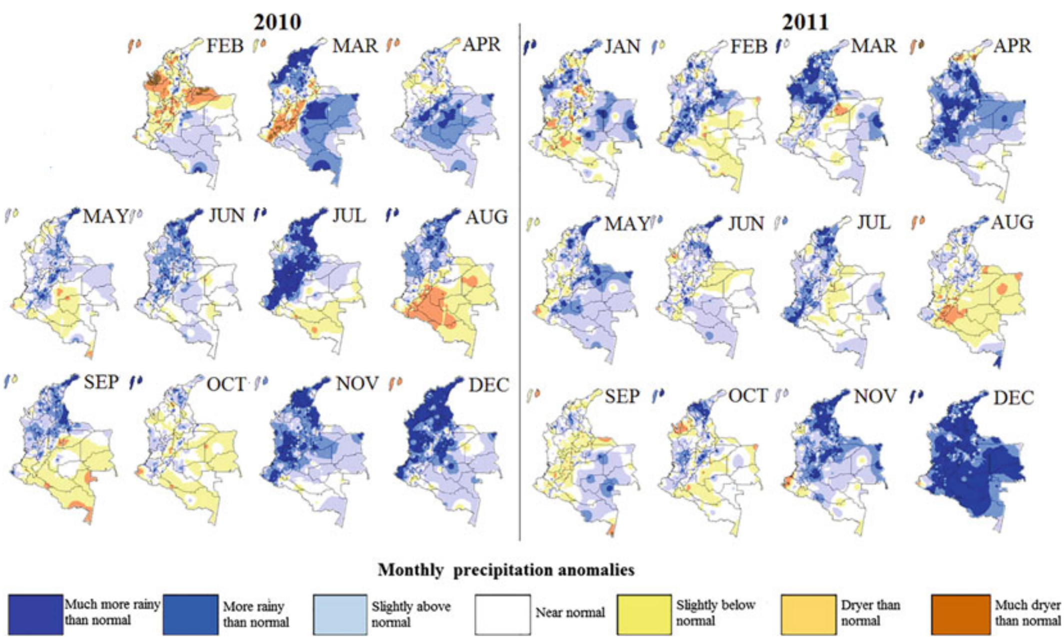

Fig. 2 Distribution of rainfall anomalies over the Colombian territory in 2010 and 2011 (in terms of the percentage of the corresponding multiannual average). This figure was created using the monthly reports published by IDEAM during the aforementioned period, as found in http://www.ideam.gov.co/web/tiempo-y-clima/prediccion-climatica

and Caribbean regions saw more than normal rainfall between April 2010 and July 2011, as consequence of La Niña 2010–2011. July 2010 is noteworthy as the rainfall recorded exceeded by 70% the historic average held for these regions. Similar increases took place in November and December 2010, when abnormally abundant rainfall covered the majority of the country, as well as in April and May 2011. This intensifying and weakening of rainfall activity is caused by the influence of intraseasonal Madden–Julian Oscillation (MJO) which are fluctuations in atmospheric pressure and wind with a 30–60 days (1–2 months) period, which move eastward from tropical western Pacific, and alternate subsidence or convection in regions over they are passing, as tropical America. As it has been established by several authors (Pabón and Dorado 2008; Pabón 2011; Torres-Pineda 2012; Yepes and Poveda 2013; Torres-Pineda and Pabón-Caicedo 2017), the convective phase of these oscillations gives way to rainfall in different regions of the Colombian territory, while the subsidence phase weakens them. The interaction of the different phases of these oscillations with the cooling of the tropical Pacific yielded this intermonthly variability in rainfall.

Analyzing the historical behavior of Madden–Julian Oscillations between 2010 and 2011 (see http://www.cpc.ncep.noaa.gov/products/precip/CWlink/MJO/ARCHIVE/), it becomes evident that there were convective phases of Madden–Julian oscillation over northern South America and the Caribbean (particularly from 60 W to 90 W near the equator), which brought about rainfall levels above normal in these months. In July 2010, when the SST anomalies had already advanced to La Niña phase (below −0.5 °C), there was a moderate convective phase of Madden–Julian Oscillation over South America and the Caribbean that furthered the effect of the cooling of the Pacific on the rainfall levels, particularly in the Andean region.

Figure 3 shows that in August, September, and October of 2010, there were strong subsidence phases of Madden–Julian Oscillation over the Colombian territory that helped to counter the cooling effect of the Pacific. However, as the latter was so strong, the rainfall did not recede completely, with excesses still over the Caribbean, the northern Andean, and Pacific regions. This means that there was no dry mid-year season as usual, with accumulations of excess humidity in the basins of the Andean, Caribbean, and Pacific regions, while the subsiding phases observed in August and September of 2010 controlled the excess rainfall. In November and December of 2010, convective phases of Madden–Julian oscillations entered the region reinforcing the effect of the cooling of the Pacific on the rainfall over different parts of the country.

In July and December 2010, when the annual cycle is usually less rainy or even dry, and when the levels of the rivers in the Andean, Caribbean, and Pacific basins diminish, the rainfall intensified over basins where there was already excess of soil moisture. Hence, the levels of the rivers did not diminish, as it is usual between two rainy seasons. This circumstance led to long flooding on the plains in the aforementioned regions.

Observed Flooding in Colombia in 2010 and 2011

By July 2010, many rivers surpassed critical overflow levels, flooding large areas in Sabana de Bogota, the Ubaté Valley, both found on the Andean plateau of the Eastern Mountain Range (the Cordillera Oriental), as well as the lowland regions of the Cauca and Magdalena rivers.

This flooding pattern continued during the second half of 2010. By January 2011, water levels began receding, though large areas remained flooded. During the second half of 2010 and the first half of 2011, the number of sudden floods and landslides in the different mountain zones of the country increased dramatically. Nonetheless, it was the long flooding of the plains that caused the greatest damage and brought about the greatest losses due to its spatial distribution,

According to a 1970–2011 analysis made by Campos et al. (2012), floods are the event that has caused the most disasters in the Colombian territory. An indicator of this: out of the

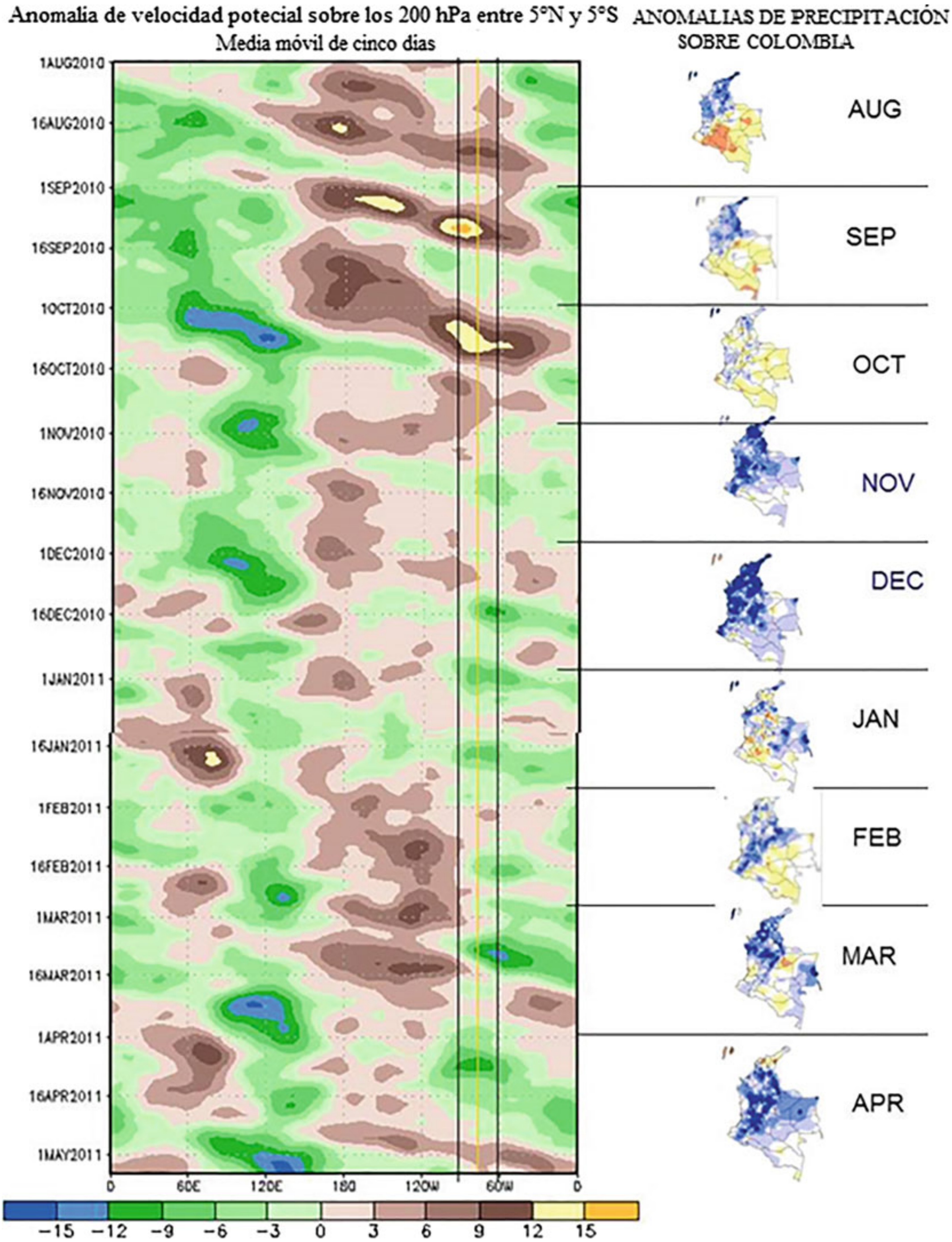

Fig. 3 Potential velocity anomaly at 200 hPa (Hovmöller diagram on the *left*) and anomalies in the monthly rainfall in Colombia (maps on the *right*) between August 2010 and April 2011. [*Blue* and *green* colors (*brown* and *yellow*) in the Hovmöller graph on the *left* represent positive (negative) values, or the convective (subsidence) phase of the MJO; the *vertical stripe* between the *black lines* indicates the longitude of northern South America; the *yellow line* shows 75°W]. Taken from Torres-Pineda and Pabon-Caicedo (2017)

1,000,000 households affected by several extreme events, 73% correspond to floods occurred within that period. Nevertheless, the disasters caused by floods of La Niña 2010–2011 widely surpassed this historic record due to their spatial extension, the number of victims, the affected property, and the government expenditure to mitigate the impacts. To have an idea about the 2010–2011 situation, it may be pointed out that the 1998–2011 period saw 3089 flood events countrywide (Güiza 2012), while from April 2010 to June 2011, there were 1734 flood events, equivalent to 45% of the floods reported for the last fourteen years.

Figure 4 shows the areas affected by the floods that occurred during the second half of 2010 and the first half of 2011. Most flooding took place in the plateau where the Sabana de Bogota and the Ubaté Valley are located. Also, the flooding affected lowlands of several sectors in Middle and Low Magdalena and Cauca basins, La Mojana region, the Sinú River lower basin, the lands located along the rivers of the Pacific region (particularly the Low Atrato and San Juan), as well as a vast sector of the Departments of the Atlántico, and Bolívar, due to the rupture of the Canal del Dique. The estimates by IGAC-IDEAM-DANE (2011) state that the area affected by floods in 2010–2011 was approximately 1,650,000 hectares, of which nearly 1,347,000 are for agricultural use, 295,000 for other uses, and 17,094 for urban zones.

The region most affected by the floods was the Caribbean, connected with the lower basin of the Magdalena River, extending between the Banco and Barranquilla cities (including Bocas de Ceniza, on the river mouth to the Caribbean). In this region, there are five subregions or hydrogeomorphologic provinces of La Mojana, Canal del Dique, and the subrecent Magdalena delta.

The La Mojana subregion is located on the lower basin of the Magdalena River with a total surface of 13.621 km^2, between the Sucre, Bolivar, and Magdalena departments. In this area, the Magdalena River branches out having the Mompos branch to the north and the Loba branch to the south. It is a lowland region with extensive flood plains, numerous marshes, and smaller streams, upon which more than 50 urban centers are located. Figure 5 features, with the aid of Landsat images, the flooded areas observed at the La Mojana subregion during 2010, compared with a dry season observed in 2015. The 2010–2011 floods covered 383.521 hectares in this subregion.

The Canal del Dique province is located between the left bank of the Magdalena River at the Calamar urban center to the Cartagena bay on the Caribbean Sea, covering a total of 1273 km^2. Three subregions or subbasins exist in this province: the high and low Magdalena and the delta. The Canal del Dique flood plain is, in its higher section, wide to the east and narrow to the west, bordering the Magdalena River valley to the east, and the Guajaro dam to the west. This plain features a swamps complex to the left border and drained out to the right. There are also signs of old channels associated to the Canal del Dique, or connectors with marshes. In this sector, the Canal is strait with an approximate length of 30 km. The mid-section of the Canal del Dique flood plain, which is from the Guajaro dam to Rocha, features a narrow and tubelike shape, with a width that varies between 3 and 8 km, thus forming a bolson of sorts at the Maria La Baja zone. The marshes in this narrow corridor are smaller and slightly elongated. The Canal del Dique delta is formed from Rocha Maria La Baja as a cone that opens toward the Caribbean Sea with a slightly dissected flat morphology, containing salt and fresh water marshes with entries of connecting channels such as Caño Correa (Vargas 2016).

On November 27, 2010, in the Canal del Dique sector located 3.3 km from the Magdalena River, due to the abundant contributions of this river, the edge of the channel presented a rupture of about 250 m in length and caused the flood of 287 km^2 of the region. Figure 6 shows two comparative views of the Canal del Dique sector, created using Landsat images, showing the 2010 floods and the situation in 2015.

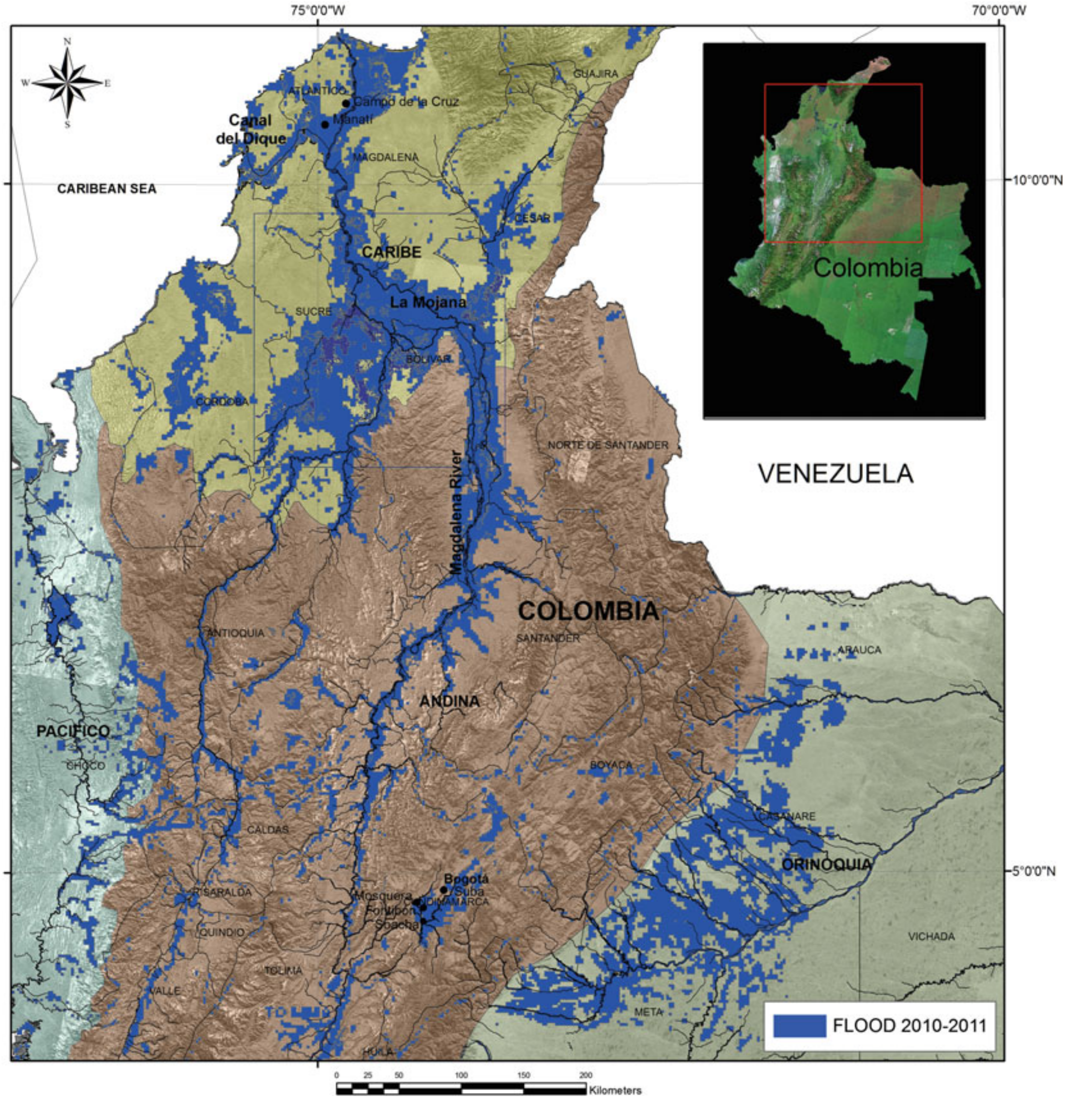

Fig. 4 Flooded zones (*in red*) in northwestern Colombia during the second half of 2010 to May 2011, adapted from IGAC-IDEAM-DANE (2011)

Socioeconomic Impacts Caused in Colombia by Flooding Associated to La Niña 2010–2011 Event

The floods occurred in Colombia between 2010 and 2011 had a negative impact on different aspects of the territory causing losses and damages to goods and service infrastructure, as well as affectation and displacement of population, a situation that constituted the greatest disaster in at least 50 years. The major damage caused by the long floods in the lower areas took place in the Caribbean region (Depresion Momposina, La Mojana, and Canal del Dique subregions) per Table 1. The Andean and Pacific regions were affected by landslides and sudden floods.

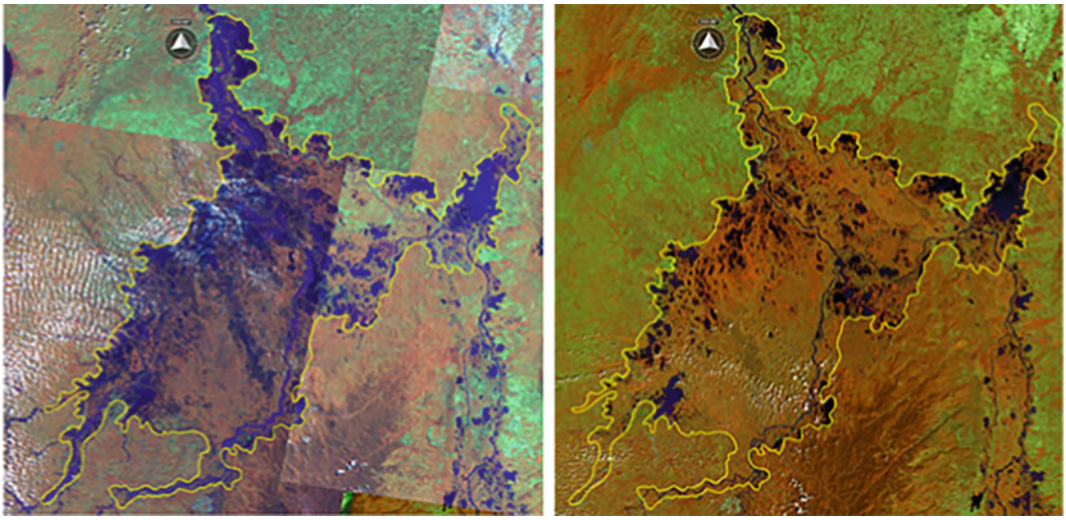

Fig. 5 Mosaic of Landsat images of the La Mojana region, corresponding to the period between November and December 2010 (*left*) and January 2015 (*right*). The image on the *left* shows the area flooded by La Niña 2010–2011. The image on the *right* shows the opposite phase (dry conditions) observed at the time, due to El Niño 2014–2016 (water covered areas in *blue*)

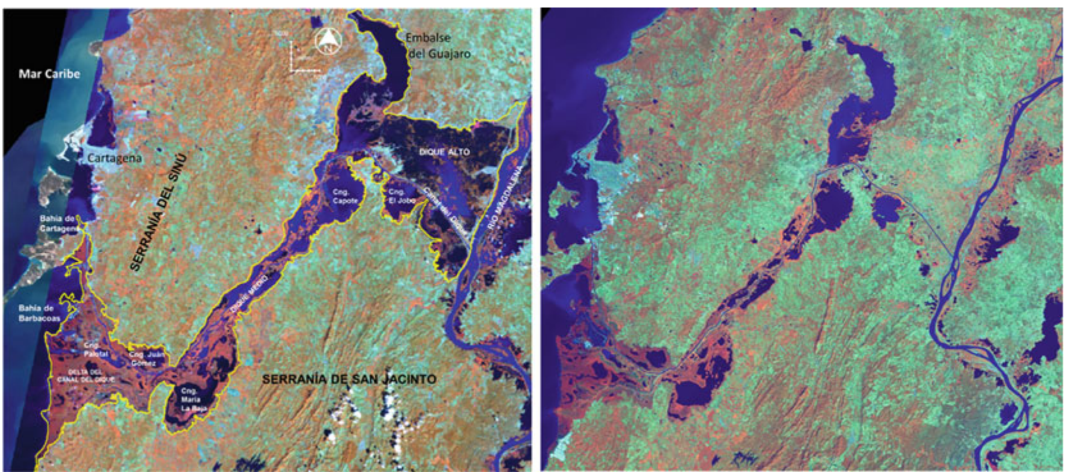

Fig. 6 Landsat images showing the Canal del Dique by January 2011 (*left*) and by January 2015 (*right*). In *blue*, the changes in the water bodies

The number of people affected by the 2010–2011 floods as recorded in the Unified Victims Registry of Colombia[1] reached a total of 3,219,239. Of these, according to Comisión Económica para América Latina y el Caribe—CEPAL, 1,577,428 were women and 1,641,811 were men; 1,158,929 were under 15 years of age,

[1]The Unified Victims Registry exists pursuant to Decree 4830 of 2010. Its purpose was to respond to the 2010–2011 emergency. Its objective was to provide the National Government with the necessary information to tend to the affected population in all different phases: humanitarian, rehabilitation, and rebuilding of zones that suffered the effects of the 2010–2011 floods.

Table 1 Synthesis of the impacts caused in Colombia by the floods associated to La Niña 2010–2011 event

Impacted regions	% of the area of department impacted	% of the total number of municipalities impacted	Impacted subregions	% of population affected in municipalities	% households affected in municipalities
Caribbean	88	98	Depresión Momposina	58.8	49.5
			La Mojana	48.1	38.4
			Canal del Dique	42.8	33.9
			Magdalena Medio	25.4	17.1
			Sinú	18.8	15.9
			Caribbean and Zona Bananera	7.1	4.2
Pacific	100	98	Valle del Rio Cauca	24.9	15.8
			Chocó Pacífico	36.6	12
Andean	100	96	Andean	5.5	3.0
Total	88	93	Total townships (394 extremely affected)	12.2	7.2
			Total impact (1.052 townships)	8.2	4.8

The data are the percentage of the affected elements (territorial area, municipalities, population, and households) in relation to the total area, total municipalities, total population, and total households of each region or territory. *Source* Comisión Económica para América Latina y el Caribe (CEPAL), Departamento Nacional de Planeación, United Nations, Interamerican Development Bank (2012), Colombia Humanitaria (case study, 2013)

740,424 were aged 16–30; 965,771 were aged 31–59, and 321,923 were aged over 59. The same registry reports 1016 missing persons and 1374 casualties (CEPAL 2012). The Atlántico, Bolivar, and Magdalena departments each reported 300 casualties and missing. 64,7% of the people registered like victims inhabited rural areas. In general, the departments with the greatest percentages of farmers affected were Casanare (90.1%), Guainía (88%), Cauca (87.6%), Nariño (81.7%), and Boyacá (79%), while urban impact was greatest in Bogota (95.6%), 14Atlántico (84.1%), Amazonas (73.5%), Caquetá (62.5%), Risaralda (58.8%), and Quindío (50%).

The hydroclimatic anomaly associated to La Niña 2010–2011 affected with special power the agricultural sector of the country. Table 2 summarizes the losses of crops and minor species affecting the income of small agricultural producers and low-income households. Additionally, the high levels of soil moisture, the low solar radiation, and phytosanitary problems (fungal and bacterial diseases) considerably reduced the yields of transitory and permanent crops. Adding to that there were problems with the cattle, such as the death of animals for several causes and the diminishing of the herd. According to CEPAL (2012), the losses of the agricultural sector added up to 764,000 million of Colombian peso (COP),[2] distributed thus: 387,450 million COP of transitory crops, 305,999 million COP of permanent crops, 23,982 million COP of meat production, 13,182 million COP of milk production, 28,036 million COP of the seafood sector (fish, shrimp; nearly 8.5 million alevins dead and over 2000 tonnes of fish

[2]By September 2011, there was the equivalence 1 US dollar = 1780 Colombian peso (COP).

Table 2 Number of households reporting agricultural losses

Total in agricultural and livestock sectors	Crops	Forests, grass	Cows, bulls, buffalos	Horses, mares, donkeys	Pigs	Other small species	Fish
591,987	481,543	155,600	152,931	101,830	183,879	455,006	58,181

Source Comisión Económica para América Latina y el Caribe (CEPAL), Departamento Nacional de Planeación, United Nations, Interamerican Development Bank (2012)

meat lost), and 4446 million COP of the poultry sector (over 600,000 birds were reported dead). Overall losses in the agroindustrial sector are estimated specifically for three representative sectors: sugar sector (36,321 million COP for price increase), banana export industry (due to a 1.1% reduction in production, 11,253 million packaging), the meat and dairy industries (9,559 million COP due to the death of 160,965 cattle heads).

A summary of the damages and losses caused by the 2010–2011 hydroclimatic anomaly on the Colombian territory is presented in Table 3.

In order to mitigate the negative impact of the 2010–2011 hydroclimatic anomaly, it was necessary to conduct interventions and develop actions that required resources from several origins, summarized in Table 4. This table evidences that the greatest investments focused on reconstruction and relocation of households, as well as the repairing of households without relocation. The handling of hazardous materials saw the lowest investment.

In sum, the overall impact became a disaster with nearly 2,500,000 affected people and large displacement of the population. This led to arising or worsening of local social conflicts, and losses and damages in excess of 14,000,000 millions COP (over 7.8 billions US dollars, using the exchange rate at the time) according to CEPAL estimates (see CEPAL 2012), which would be almost 2% of 2011 Gross Domestic Product—GDP (estimated by Rendon-Acevedo (Rendón-Acevedo 2012) as 335,000 million USD).

Table 3 Estimate (in million COP; see the footnote for the equivalence in US dollars) of damages and losses caused by the hydroclimatic anomaly associated to La Niña 2010–2011 on different sectors

Sector	Damages	Losses		
		Subsectors	2010	2011
Housing: environmental, housing, water, and sanitation	4,907,531	Housing	46,383	46,383
		Industry and Tourism	125,914	32,861
		Mining	608,000	0
Social services and public administration: education, health, family welfare, culture, sports facilities, police force, and official entities	1,251,103	Social Sectors	6069	6069
Infrastructure: transportation and energy	4,267,804	Transportation	142,699	275,063
		Energy, gas, and water	17,220	4368
Productive: agricultural and non agricultural	806,695	Productive: agricultural and non agricultural	136,453	709,618
TOTAL	11,233,132		1,082,738	709,588

Source Comisión Económica para América Latina y el Caribe (CEPAL), Departamento Nacional de Planeación, United Nations, Interamerican Development Bank (2012)

Table 4 Costs (in million COP) of mitigation works and other interventions by sectors

Mitigation works	Costs	% Investment
Flow management	852,363	17.75
Management of unstable slopes	266,154	5.54
Control and retention of sediments	35,698	0.74
Stabilization of streams	40,134	0.83
Hazardous materials management	1160	0.024
Non-structural measures (studies)	4934	0.10
Reconstruction and relocation of households	2,707,978	54.41
Repairing of households without relocation	891,934	18.58
Total	4,800,355	100

Source Comisión Económica para América Latina and the Caribbean (CEPAL), Departamento Nacional de Planeación, United Nations, Interamerican Development Bank (2012)

Overview on Social Aspects Observed in Flooded Territories During 2010–2011

The floods that took place in Colombia in the second half of 2010 and first half of 2011 evidenced some social realities, particularly concerning the vulnerability of the territories facing the effects of extreme hydroclimatic events. The disaster underlined diverse human and social faces. Over an altered regional physical environment by the floods, different situations and interests on the territory emerged. Detailed analysis of these situations was conducted by Hernández-Peña (2013). Following in this sub-chapter, a few events and situations are recounted.

In townships Campo de la Cruz and Manatí (Atlántico department), for instance, the bio-physical and socioeconomical realities of the territories were hidden under water by the floods. All of this gave way to a public perception of "disappearing townships," which made the functioning of public institutions even more difficult, as well as the necessary action in critical areas and the mitigation of the impact. In addition to the damages and losses to the heritage of the families (houses of approximately 555,400 households were impacted), and to their means of living (over 600,000 families with agricultural losses), there is the drama of forced displacement due to the floods. A large portion of the displaced population had to relocate to improvised shelters in the form of tents, repurposed schools, the homes of relatives and friends who took them in, or rentals, in many cases in foreign territories and difficult conditions.

The Campo de la Cruz municipality (Atlántico department) was one of the most affected by the floods. The entirety of the township was covered by water, forcing all its inhabitants to relocate, with many of them doing so in tents. The people who lived in these improvised shelters did so in inhuman conditions (overcrowding, excessive heat, lack of drinking water). For that reason, many people chose to return to the few dry areas left in the township, settling anywhere. However, when the relocation of the affected population was proposed, people did not agree to it because, as they said, *"by the road people see us better and help us more."* See Fig. 7.

In Campo de la Cruz, diverse social problems and conflicts were observed at the concentration sites for affected population. In addition to disputes over humanitarian aid, the difficult conditions led to violent demonstrations due to general malcontent. There were also territorial disputes. The police and other entities reported drug abuse problems among the youth of some of the shelters.

Several sectors of the Colombian Andean region were affected by the floods. Among them was the Sabana de Bogota, the mid-basin of the

Fig. 7 View of the flooding at Colegio Campo de la Cruz (photograph on the *left, upper panel*); tents used by displaced population by the Campo de la Cruz floods (photograph on the *right, higher panel*); the moment when a group of people displaced by the floods in the Caribbean region asks for help by the road (*lower panel* photograph). Photographs by Yolanda Hernandez

Bogota River, located on the plateau of the Eastern Mountain Range (Cordillera Oriental). The overflow of the Bogota River flooded large sections of the Cajica, Chia, Cota, Suba, Madrid, Mosquera, and Soacha townships, as well as those areas within Bogota located along the river. In the case of the Mosquera township, located to the east of the Sabana de Bogota, the overflow and subsequent flood occurred due to the breaking of a dam that contained the river (Fig. 8). These floods happened in December 2010.

The Soacha township was one of the most affected by the floods in the Sabana de Bogota during 2010 year, in particular, by the overflow of the Soacha River. It is of note that though there was an abnormal increase in rainfall and in the overflow of the rivers and floods; it is also evident that there was mismanagement of the water sources and poor territory planning, not only in Soacha but also in the Bogota River basin, as well as in other regions affected by the floods, all of which worsened the effects thereof. This is easily evidenced by the practice of depositing residues on the riverbed of the Soacha River, thus blocking its course. Similarly, many urbanizations were built nearby without a sewage network.

There were difficulties responding to this emergency, including differences between the politicians and the community regarding the order of priorities. An inhabitant of Soacha declared that the mayor's office had failed to offer help to his neighborhood, despite numerous

Fig. 8 Flooding of a nursery in Mosquera, Cundinamarca (on the *left*); a meeting of victims from Soacha by a community potluck (on the *right*). Photographs by Yolanda Hernandez (December 2010)

requests for civil works to be set in motion to overcome the situation. The statement also pointed out that construction of the sports and community center for the VI neighborhood was given priority. This was a massive and expensive work that took priority at the time of the emergency. The community was skeptical of the decision as the emergency did not require the construction of the sports center, but rather repairs for the neighborhood. The photograph on the right in Fig. 8 shows the situation observed in the neighborhood in question related to the distribution of humanitarian aid by the Vision Mundial NGO and the activities the victims assumed, such as the preparation of their meals.

Conclusions

The strong hydroclimatic anomaly observed during the second half of 2010 and the first half of 2011 caused by the La Niña phenomenon, impacted the Colombian territory severely. This anomaly led to unusually abundant rainfall and a high frequency of extreme events such as sudden floods, overflows, landslides, long-lasting floods in extensive areas, all of which amounted to an extraordinary situation not seen for at least 50 years. The long-lasting floods in extensive areas were the event that most affected the population, the productive and housing infrastructure and the diverse socioeconomic sectors, generating a disaster of enormous proportions: nearly 2,500,000 victims, displacement of much of the affected population due to flooding of their territories, arising or worsening of local social conflicts, and damages and losses in excess of 14,000,000 millions COP (over 7.8 billions USD), or nearly 2% of the 2011 GDP.

This adverse experience highlighted several dramatic situations and social conflicts in different parts of the country, which in turn brought to light many important aspects of the vulnerability of the communities facing hydroclimatic hazards and failures in the risk management system, which is a responsibility of the State in its many forms.

Among the identified aspects, the following stand out: the disparity between the politicians responsible for the planning and the community, regarding the priorities of risk management in territorial development; the poor planning of the emergency response scheme (important for risk management) which delayed the aid and allowed the worsening of conflicts in temporary allocation areas for victims. These findings may serve as a lesson to strengthen the risk management of this type of extreme events and be better prepared in the future.

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The Experience of Disaster Risk Reduction and Economic Losses Reduction in Malaysia During the Water Crisis 1998 in the Context of the Next El Nino Strongest on Record Maximum 2015

Leonid V. Sorokin

Abstract

The Sendai Framework for Disaster Risk Reduction 2015–2030 is aimed at action to prevent new and reduce existing disaster risks. Climate warming leads to the climate anomalies that have increased the number of extreme weather-related events two times for past 10 years. Natural disasters are one of the main sources of risks and economic losses in modern time. The annual economic damage for the India from natural disasters is about 2% in terms of gross domestic product (GDP). The projected earth climate change can increase the economic losses to a considerable extent. In certain regions, the increasing of the average temperature leads to the precipitation anomalies and changes in their characteristics such as duration, intensity and severity. Corresponding to them, the economic losses and risks are increasing. The economic efficiency of chemical free weather modification and creation of artificial precipitations during the droughts, forest fires and heat waves are underestimated. One of the drought consequences is either water shortage or water crisis. Targeting artificial rain clouds in the dams' catchment areas can solve the problem of the town water supply during the drought. Targeting artificial rains in the agricultural regions and forests can be also effective for minimization of drought sequences and reduction the risk of vegetation fires. The main idea for Disaster Risk Reduction and reduction of economic losses from droughts is cutting the peaks intensity and reduction of the event duration that will lead to a reduction of the event severity. The basic idea for risk minimization and economic losses reduction from flooding is to move

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excess water to areas with water shortage. The innovation methods of managing the crisis with the help of modern technical solutions as chemical free weather modification can considerably reduce the economic losses from natural disasters.

Keywords
Disaster risk reduction · Water crisis · Climate change · Economic losses Weather modification · Artificial precipitations · Water supply · Flood Drought · Vegetation fires · Haze · Smog

Introduction

The Sendai Framework for Disaster Risk Reduction 2015–2030 is aimed at action to prevent new and reduce existing disaster risks. The solutions for Disaster Risk Reduction should be based on the strong scientific background and expertise. This is mostly important for the decision-makers and political decision-makers. The climate change consists of four components: temperature change, precipitation change, sea level rise and extreme weather-related events (IPCC 2007). All these lead to such consequences of climate change as follows: water deficit, vegetation fires with haze and smog, droughts and floods. The climate change effects can be periodical, long-term and short-term. The long-term duration changes can be taken into account in the formation of adaptation strategies for new climate conditions. But the extreme weather conditions usually are short-term duration ones; they are unexpected and, thus, add to the economic losses. Under certain conditions, the economic losses from the extreme weather-related events are also localized in time and space. In this context, the possibility of economic losses reduction from climate change exists and the new methods and technologies are very expected.

The floods, droughts, forest fires and haze can be separated from the list of extreme weather-related events as highly localized in space and time. The main characteristics of these events are the following: geographical localization, short-term duration, event severity and the technology existence for economic losses reduction. Two main components responsible for the climate change they are as follows: natural climate trend and the human activity. The most significant natural sources of greenhouse gases (GHG) emission are volcanic eruptions and animals. From another side, the Ocean contains the main deposit of greenhouse gases. The most dangerous from greenhouse gases is the methane (CH_4) due to methane hydrate huge deposit in the Ocean and the higher global warming potential compared with carbon dioxide (CO_2). The global warming (GW) can provoke the catastrophic emission of methane hydrate that can intensify the mean temperature increase. In the present time, the humanity affects the climate more than the natural variations. It depends on human activity how large this effect could be. The most dangerous activities are energy generation, transport and industrial production, destruction of forests and ecosystems.

Thus, we can conclude that humanity has a negative impact on the earth's climate system, but this state of affairs is unacceptable. If the humanity was able to influence the earth climate system, then it would be reasonable to assume that it should take some steps to correct their mistakes. Two conclusions follow from this: the first is to abandon the activity which is detrimental; the second one is to take steps against adverse climate change. In our days, the humanity does not have the technology to influence the earth climate system in the desired direction. Fortunately, not every component of climate change can be dangerous for the humanity, but the extreme weather-related events such as floods and droughts can add to the economic losses.

Other important parts of economic damage happen due to droughts consequences of climate change are as follows: losses in agriculture, water crisis, water shortage, forest fires and haze, mortality, wars for resources, armed conflicts and refugees. The standard measures for overcoming climate change consequences are the politics of migration and adaptation. But in the case of extreme weather-related events, the adaptation is not effective due to the relatively short duration of the event. The extreme weather-related events are not regular, highly localized in space and time, and have widespread geographical localization. This leads to huge investments in the infrastructure and payments of insurance companies. Some of the insurance companies can stop its participation in the programs from risks of extreme weather-related events.

The adaptation strategies are aimed at long-term duration changes for the new climate conditions. The mean temperature can increase smoothly, but the lowest and highest temperature variations can increase significantly, that rises the number of extreme weather-related events (Sorokin 2012b). This effect was described by Katz and Brown (1992) in their paper on extreme events in a changing climate. They used the statistical theory for extremes to demonstrate that the frequency of extreme weather-related events is relatively more dependent on any changes in the variability than in the mean of climate.

Further research "Increase of extreme events in a warming world" by Rahmstorf and Coumou (2011) study the effect of warming trends on heat records, using analytical solutions and Monte Carlo simulations. They find that the number of record-breaking events increases approximately in proportion to the ratio of a warming trend. This effect was perfectly investigated on the base of the huge meteorological data (Hansen et al. (2012) and explained in the J. Hansen and M. Sato (2016) paper: "Despite the small magnitude of warming relative to weather fluctuations, effects of the warming already have notable social and economic impacts. Global warming of 2 °C relative to preindustrial would shift the 'bell curve' defining temperature anomalies a factor of three larger than observed changes since the middle of the 20th century, with highly deleterious consequences".

Another important question is the relation of GHG concentration and a rate of global warming. The estimation of the climate sensitivity for doubled CO_2 concentrations of about 3 °C was done by M. Previdi et al. (2013). Taking into account, the deforestarisation and ice sheet/vegetation albedo feedback the GW can rise up to 4–6 °C (Previdi et al. 2013). But it is possible to stabilize the earth climate in the case of GHGs emission reduction (Hansen et al. 2013). Cooling Ocean surface in the North Atlantic with the simultaneously warming southern Ocean surface provides the increase in the atmosphere kinetic energy and that can drive more powerful storms (Hansen et al. 2016). On the J. Hansen et al. (2016) expertise, the 2 °C global warming above the preindustrial level is highly dangerous.

Max Planck Institute for Chemistry (MPIC) in Germany provides a research on long-term meteorological data sets and climate modelling for socioeconomic and population projections. The MPIC research area (the Middle East, North Africa and eastern Mediterranean) is common to the Indian weather conditions, so it is possible to refer to their model results. In this century, the Middle East and North Africa can be affected by climate change, associated with increases in the frequency and intensity of droughts and hot weather conditions (Lelieveld et al. 2012). They project the increasing heat extremes, accelerating in future and very hot summers that occurred rarely in past are projected to become common by the middle and the end of this century (Lelieveld et al. 2014).

In the recent research, J. Lelieveld et al. (2016) make a frightening forecast: "On average in the Middle East and North Africa, the maximum temperature during the hottest days in the recent past was about 43 °C, which could increase to about 46 °C by the middle of the century and reach almost 50 °C by the end of the century, the latter according to the RCP8.5 (business-as-usual) scenario". This will have outstanding consequences on the Middle East and North Africa—550 million population from

29 countries. The climate conditions in the huge area can be uninhabitable or dangerous for human health that can start the new wave of refugees. The most unexpected for decision-makers' MPIC result is 4 °C global warming above the preindustrial level, by the middle of this century. So this can happen two times faster and two times higher than it was planned (2 °C) by COP21 in Paris 2015.

Droughts and hot weather conditions frequently accompanied by dust storms and forest fires with a haze that leads to air pollution and mortality (Pozzer 2012a, b). The highest mortality rates are in the Southeast Asia (25%) and western Pacific regions (46%) (Lelieveld 2013). The air pollution could double mortality by 2050 (Lelieveld et al. 2015). And the death toll from air pollution sources was studied by M. Jerrett (2015).

In the modern time, the climatic migration and ecological migration create the new threats to the population of countries exposed by natural disasters. The political borders try to stop the uncontrolled migration, but it increases the political and economic tension. So the water shortage and water crisis lead to wars for resources, water wars, armed conflicts and for a huge number of refugees. In the conditions of the world economic crisis the growing migration increases that leads to political and social tension and causes to the additional economic loss. At the same time, India is affected by severe droughts and floods that multiply the economic damage. The annual economic damage for the India from natural disasters is about 2% in terms of gross domestic product (GDP). The economic cost due to the climate migration and adaptation for extreme weather-related events can be huge. The next strongest on record El Nino maximum can cause to huge natural disaster in Southeast Asia region with drought, forest fires and haze. This can also affect India and the Middle East region.

The Strategy for Reducing Economic Losses from Natural Disasters

In the case of rapid climate change, we can face the high cost of anti-crisis measures and the inconsistency of the old infrastructure to new climatic conditions. In this regard, there is an urgent need to find effective methods to minimize the economic damage from extreme weather conditions. The optimal solution to minimize the damage could be a redirection of excess water to areas with a shortage of them, which would reduce the depth, bought for floods and droughts (Sorokin 2012b). The use of innovative chemical free and ground-based weather modification technologies could solve the problem of water shortage in a limited area by the creation of artificial precipitations. Thus, it is possible by means of ground infrastructure to move the rain clouds in the area with a shortage of water resources and to cause the precipitation there. So the basic idea for risk minimization and reducing economic losses from flooding and droughts is to move excess water to areas with water deficit (Sorokin 2012b).

The extreme weather-related events have the measured parameters: duration, intensity and severity. The economic losses from the extreme weather-related events can be significantly reduced by cutting the peaks intensity and reduction of the event duration that will lead to a reduction of the event severity (Sorokin 2012b).

Targeting artificial rain clouds in the dams' catchment areas can solve the problem of the town water supply during the drought. Targeting artificial rains in the forests and agriculture regions can be effective for minimization of drought sequences. Artificial precipitations influence on the vegetation fire situation can reduce hot spots number in times. The most effective tactics for prevention the vegetation fires is reducing the Fire Danger Rating (FDR) by increasing the volume of artificial precipitations in the target area (Sorokin 2012a). Weather modification can be helpful for reducing the smog and haze concentrations or for the air ventilation of huge volumes (Sorokin 2012a).

A large number of countries outside the India and their own interests could create problems at the level of making a decision. Thus, the risk groups are following: political; the absence of a decision on the anti-crisis measures in due time; long overdue decision after a disaster or a water crisis.

Thus, the reduction of economic losses from extreme weather events (Sorokin 2012b) is possible due to:

- fast response;
- weather modification;
- creation of artificial rain clouds and precipitations from them;
- reducing of drought and fire danger index by creating artificial precipitations (soaking the territory);
- redistribution of plenty water recourses from wet to dry place for minimization of sequences from flood and drought;
- decrease of the intensity of the event;
- reduction the duration of the event;
- reduction the depth of the event;
- accumulation of a reserve stock of water in the reservoirs.

Economic Losses from Droughts in Southeast Asia

The El Niño climatic disturbance can multiply the depth of the drought period that had been happened in the periods 1982–1983, 1994 and 1997–1998. The drought year 1997 was the worst on record for forest and bush fires all over the world, especially in the tropics and the subtropics countries. The drought affected many countries of the world (Indonesia, Brazil, Malaysia, Singapore, Australia) and the regions of Southeast Asia, Pacific, Latin America and Africa were caused by the most severe El Niño event ever recorded. Catastrophic fires occurred in Indonesia and the haze from them covered the Malaysia, Singapore and Australia so that it was seen on the satellite images. The Malaysian peninsular was severely affected by smoke blowing from Indonesia, the people complained of health problems, schools and businesses were closed. The electronics plants producing microprocessors and computer memory were closed due to the bad air conditions. The Economy and Environment Program for Southeast Asia (EEPSEA) and the World Wide Fund for Nature (WWF) provided the economic research (EEPSEA and WWF, 1997) of the Indonesian fires and haze of 1997, (Golver 1999) and reported: "The total economic value of these damages are conservatively estimated to be US$ 4.47 billion, by far the largest share of which was borne by Indonesia herself. This figure excludes a number of damages that are especially difficult to measure or to value in monetary terms, such as loss of human life, long-term health impacts and some biodiversity losses. Nevertheless, these enraptured damages are real and will be felt, directly or indirectly, by many of the inhabitants of the region". Among them, the loss of Indonesia from the fire was 2787.9 million USD and haze-related damages were 1012 million USD. The loss of other countries from the fire was 285.5 million USD and haze-related damages—384.1 million USD.

The catastrophic air pollution situation was illustrated by NASA composite image of enormous impact on carbon emissions (Fig. 1). The haze thickness was about 2.5 km and the visibility was less than 20 m in the Malaysian capital Kuala Lumpur. In this condition, in some regions of Malaysia, there was no rain for half a year. The economic loss due to 1997 drought and haze in Malaysia was RM (Malaysian Ringgit) 794.3 million (excluding firefighting costs), among them: health damages—RM 20.1 million; industrial production losses—RM 393.5 million; tourism—RM 318.5 million; airline and airport losses—RM 0.5 million; decline in fishing—RM 40.6 million; cloud seeding—RM 2.1 million. Total 1997 drought and haze Malaysian regional costs estimated USD 1.4 billion (NST 1998).

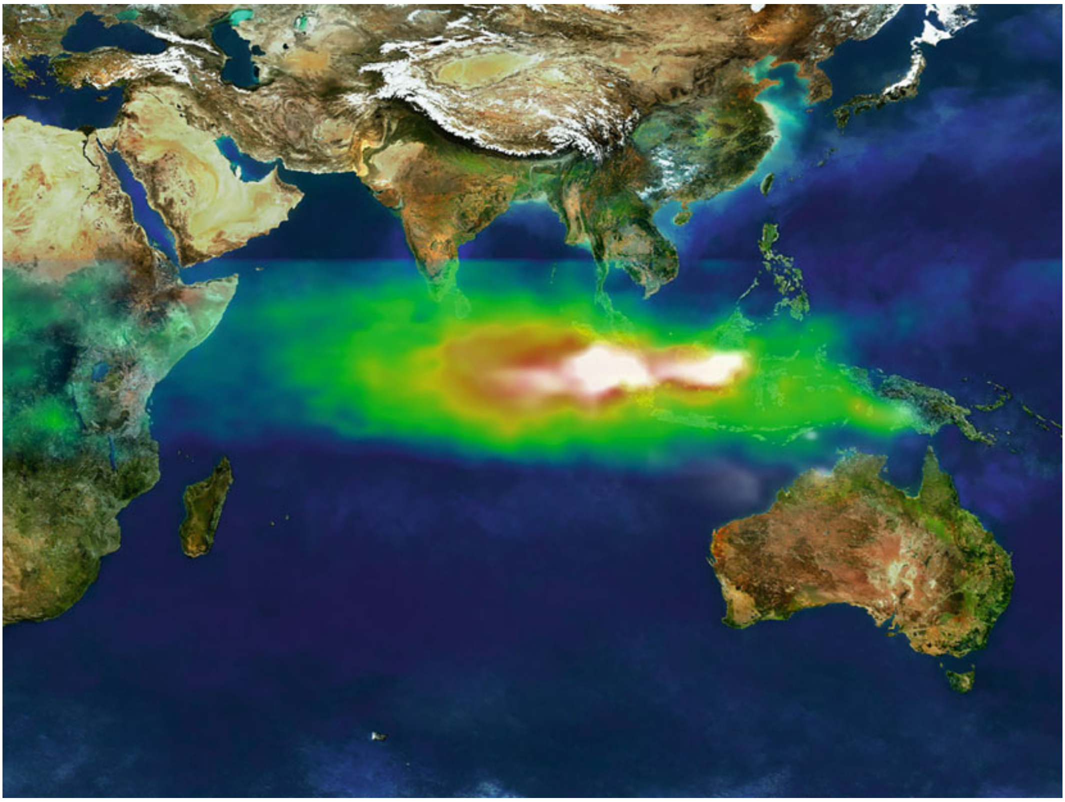

Fig. 1 In the second half of 1997, smoke from Indonesian fires remained stagnant over Southeast Asia while smog, which is tropospheric, low-level ozone, spread more rapidly across the Indian Ocean towards India. *Source* Credit Image courtesy NASA GSFC Scienific Visualization Studio, based on data from TOMS

The economic losses in 1998 were on a par with the previous year. In the Hety Herawati et al. report (2006) on the project meeting of the Tropical Forests and Climate Change Adaptation (TroFCCA), the total amount of drought and fires mean economic costs in the period 1997–1998 estimated as 9158 million USD. The next El Niño strongest on record maximum 2015 with the forest fires and haze can cost for Indonesia USD 47 billion (StraitsTimes 2015) and the total sum is under estimation. This is more than 4.5 times than the total loss from the forest fires and haze in this region during the El Niño 1997–1998.

Weather Modification

In general, it is impossible to influence climate and its periodical weather variations with extreme weather-related events, but it is possible to cut the water deficit due to the diversification of water recourses and conduct the weather modification for attracting additional water resources, providing the economic losses minimization (Sorokin 2012b). For different extreme weather events, the different strategy and technology can be effective for economic losses reduction. State and outlooks of the regulation of weather conditions in the XX century were done in review (Sorokin and Zapareey 2000). The methods of weather modification are quite different from cloud seeding with chemical reagents up to the electrical field and electromagnetic emission. All methods are very specialized; they have been developed for certain weather conditions and have a number of technological limitations.

The chemical free and ground-based weather modification method was successfully used (Sorokin 2012c) in Russia (1989–1997, Moscow region) and in other places from Equator region (June–July 1998, Malaysia) up to the Polar Siberia (February 1999, the Sakha Republic, Russia). The main success of this method is the stable operation in wide range of conditions: extended temperature range from −20 °C up to +38 °C, humidity range 30–80%, altitude up to 2000 m (Sorokin 2012b). The weather modification method was applied for air ventilation of huge volumes, the cloud formation from a clear sky, guiding the cloud up to the distance of thousand km, targeting the clouds in the dams' catchment areas and provoking the precipitations, fighting with forest fires and haze (Sorokin 2012c).

Chemical free and ground based weather modification can operate in the extended temperature range and can grow up the clouds from the clear sky (Sorokin 2012c). This is the main advantage during the extreme drought conditions when the weather modification based on chemical reagents and cloud seeding is useless. As an example, in this paper, we provide the estimation of weather modification efficiency for Disaster Risk Reduction and economic losses reduction from extreme drought in Malaysia and Indonesia 1997–1998.

Artificial Rains for the Water Supply End Agriculture Purposes

The El Niño climatic disturbance and the drought with forest fires lasted on 1998. Just in this time, the author was invited to participate in the Malaysian research team (during the period, April and June–July 1998) for climatological expertise and weather modification. The work has been carried out under the firm "Bio Cure" Sdn Bhd by the order of the Malaysian Government. For the purpose of the town region water supply, the dams are constructed in the closest highland areas. The place of dam construction depends on the distance to the town and from the catchment area surface. During the period of intensive rains, the dam is filling with water, accumulating the water deposit. Later, in the droughty period, the accumulated water is used for the water supply of the town. During the one year drought, the water deposit in the dam is enough for standard requirements, but long duration drought can drop the water level in the dam to the critical level that will stop the water supply. That had happened in Malaysia 1998 during the drought period, when the rains were absent or rear.

In 1998, the Malaysian capital Kuala Lumpur received water from four dams: Sg. Langat dam, Semenyih dam, Klang Gates dam and Tasik Subang dam. The biggest of them Semenyih dam and Sg. Langat dam were the principal suppliers of water for the Kuala Lumpur. From 14 June to 23 July 1998, the water level in all the dams was maintained closely to the critical level and the water supply of Kuala Lumpur was reduced for some hours (Sorokin 2012a).

The main aim of this research was the chemical free weather modification approbation during the extreme droughty period in Southeast Asia region and confirmation of the commercial efficiency of this method. Other aims were the water supply recovery and the minimization of loss from forest fires and haze. The weather modification is very useful for the formation of the rain clouds. Targeting artificial rain clouds in the dams' catchment areas can solve the problem of the town water supply in some conditions. Targeting artificial rains in the forests and agriculture regions can be effective also for minimization of drought sequences. The rains and thunderstorms are clearing the air from smog and haze, so the air conditions become better (Sorokin 2012a).

The experiments on chemical free and ground based weather modification were carried out all over the Malaysian peninsula in different climatic areas, as well as in Kuala Lumpur dam's catchment areas. We provided a series of 14 experiments in 8 different places all over the Malaysia. During the experiments on weather modification and creation of artificial precipitations (Sorokin 2012a) in Malaysia (June–July 1998), we provided monitoring in the places of the work, collected data from the dams, used meteorological data from the Malaysian Meteorological Service (MMS) and the Meteorological Service Singapore (MSS), received satellite images (clouds, water vapour, hot spots of fire and haze) and use radar images.

During the period of the work, MMS was equipped with: 33 principal meteorological stations, 99 climatological stations and 142 rainfall stations. Most of the principal meteorological stations provided hourly or 3 h meteorological data. Climatological stations and rainfall stations provided 12 h and daily meteorological data. Malaysia disposed of 8 upper air stations, 7 storm warning radar stations, 5 meteorological satellite stations and lightning detection network (LDN). Government lightning expert provided information on lightning situation.

In the experiments on weather modification, the artificial rain clouds formation efficiency depends on the place and weather conditions. Some clouds are created over Malaysian peninsula produced precipitations for 2–4 days after experiments and gone on a distance 600 km and more (Sorokin 2012b). The duration of weather condition normalization process in the Equator region was from one up to two weeks and depends on the amount of precipitations, wind speed, temperature and evaporation cycle (Sorokin 2012a).

During the period of operation June–July 1998, the water level at the dams was maintained at a very consistent level due to the fact that the water trapped in the catchment areas was at par with the water supply to the public at large. Due to this fact and dividing the total Water Production on the total Rainfall at the catchment area, we made an estimation of water production of the dams' catchment areas in the 40 days period from 14 June–23 July 1998.

The Sg. Langat dam produces 30.659 million litres of water on each millimetre of the rainfall at the catchment area. The Semenyih dam produces 71.507 million litres of water on each millimetre of the rainfall at the catchment area. This balance does not take into account the volume of water accumulated in the soil. Eight experiments (Sorokin 2012b) in five places were targeted at the catchment areas: Fraser's Hill (14 June 1998); Hulu Langat dam (20 and 21 June 1998); Ulu Langat, Kuala Klawang (4 and 5 July 1998); Gohtong Jaya, Genting Highlands (10 and 12 July 1998); Bukit Kiara, Kuala Lumpur (19 July 1998).

Six other experiments (Sorokin 2012b) in three places were not used in our analysis because the rains were not targeted in catchment areas. In Janda Baik (6 and 9 June 1998), there was no data from dams during the experiment. In the experiment Ulu Yam (27, 28 and 30 June and 1 July 1998) heavy rain was far from the dam, in Fraser's Hill, due to the wind direction. And the experiment in Gunung Raya, Langkawi (16 July 1998) was carried out too far from the dams (about 800 km), and the rain was over Langkawi.

The analysis (Tables 1 and 2) is based on Water Production and Rainfall data from Semenyih dam and Sg. Langat dam—the principal water suppliers of the Malaysian capital Kuala Lumpur and covers the 40 days period (14 June–23 July 1998). The dams' rainfall stations acuminated rainfall data within one day (0–24 h). Due to the fact that the artificial rains started in the evening and continued after the midnight or up to the morning, a part of precipitations in the experiments on weather modification was registered in the day of weather modification and the rest–the next day. During selected eight experiments (targeted at the catchment areas), we had six events with precipitations on the next day after the weather modification. So we use for the analysis all 14 days which were directly affected by the weather modification (Sorokin 2012b). All other 26 days we use for analysis of the relaxation process.

In Table 1, it is clearly seen that water production from Sg. Langat dam during the days of weather modification (Sorokin 2012b) and on the

Table 1 Water Production and Rainfall at the catchment area for Sg. Langat dam

From 14 June up to 23 July 1998	Rainfall at the catchment area (mm)	Water production (million litres)	%
At the day of weather modification (8 experiments)	127.0	3893.69	37.61
The next day after the weather modification experiment (6 events)	58.7	1799.68	17.38
All other 26 days	152.0	4660.17	45.01
Total (40 days period):	337.7	10,353.54	100.00

Source Sorokin (2012b)

Table 2 Water Production and Rainfall at the catchment area for Semenyih dam

From 14 June up to 23 July 1998	Rainfall at the catchment area (mm)	Water production (million litres)	%
At the day of weather modification (8 experiments)	62.8	4490.64	24.13
The next day after the weather modification experiment (6 events)	67.3	4812.42	25.85
All other 26 days	130.2	9310.21	50.02
Total (40 days period):	260.3	18,613.27	100.00

Source Sorokin (2012b)

next day after them was 54.99% and all other 26 days—45.01%. The same picture we can see in Table 2. So the water production from Semenyih dam during the days of weather modification (Sorokin 2012b) and on the next day after them was 49.98% and all other 26 days—50.02%.

We can see that 14 rainfall days affected with weather modification was only 35% from taken period of 40 days. The total water supply of the Malaysian capital Kuala Lumpur from Semenyih dam and Sg. Langat dam in the 14 days affected with weather modification was 14,996.44 million litres or 51.77% from the whole volume within 40 days period (from 14 June to 23 July 1998). So we can conclude (Sorokin 2012a, b) that the efficiency of weather modification within the period (14 June–23 July 1998) of severe drought in Malaysia was more than two times!

The analysis of Malaysian droughts and its characteristics were studied in the National Hydraulics Research Institute of Malaysia and in the Department of Irrigation and Drainage. The estimation of duration and termination of the drought affecting Langat Valley was made using the Herbst method by Ahmad et al. (2004). Ahmad Jamalluddin et al. (2004) estimated Langat Valley drought characteristics: average monthly drought intensity as 2.25; duration of 6 months; index of drought severity as 13.5; drought severity ranking as 6; 43.7% of mean rainfall for drought period; drought onset since 1 December 1997 and potential end of drought after 30 May 1998.

So taking in account that the Herbst method based on mean monthly rainfall data the termination of the drought affecting Langat Valley was due to the increasing the rainfall in June 1998, and its 54.99% income was due to the experiments on weather modification (Sorokin 2012b). The experiments on weather modification (Sorokin 2012a) brought the weather conditions close to the normal ones in the dams' catchment areas. But it takes a long period of time to fill the dams with water.

The Fraser's Hill Experiment

On 14 June 1998, we have made a weather modification experiment in Fraser's Hill Highland area on creation an artificial rain cloud and provoking a rain from it. The artificial cloud (Fig. 2) was well seen on the satellite image (08:03 GMT, 14 JUNE 1998, image produced by Meteorological Service Singapore). This cloud provided a heavy rain and thunderstorm. The artificial nature of this cloud is clear due to the fact that in the morning (00:30 UTC 14/06/1998 confirm by Meteorological Service Singapore) there were no clouds over Malaysia peninsular, and in the daytime, it was the single cloud launched from the Fraser's Hill during the experiment.

The heavy rain was traced from Fraser's Hill, passed through Kuala Lumpur and went in the direction of Sumatra (Riau Province). At night from 14 to 15 June, the clouds reached the Kuala Lumpur dam's catchment areas (Fig. 3). Luckily, on the way of this cloud, there were a big number of Indonesian forest fires. During 15–18 June, a number of clouds were still producing the rains. The whole process of weather normalization after experiments on the creation of artificial rain clouds usually takes about one week (Fig. 4). Some artificial clouds created over Malaysian peninsula were able to produce precipitations for 2–4 days after experiments and gone on a distance of 600 km and more.

The Vegetation Fires

Just at that time in Indonesia, the EU-Forest Fire Prevention and Control Project (FFPCP) was struggling against vegetation fires. With the kind help of the FFPCP the Project Leader Dr. M. Roderick Bowen, it was possible to trace the effect from Fraser's Hill cloud on the fire situation over Sumatra. Corresponding to FFPCP data (Anderson 2001) on monthly, a total number of hot spots in each Sumatra province on June 1998 are the following: Riau (3057), North Sumatra (728), West Sumatra (296), Jambi (97), Aceh (37), Bengkulu (34), South Sumatera (16) and Lampung (6). The total number of hot spots in all Sumatra provinces was 4271 (June 1998).

The vegetation fire situation on Sumatra, 14 June 1998 (Anderson et al. 1999, Anderson 2001) one can see the Fig. 5 and in the box is enlarged hot spot map of Riau province (Anderson et al. 2000). At the day of weather modification experiment 14 June 1998 on Sumatra, there were detected 835 hot spots (Fig. 6a). During the period from 15 up to 16 June 1998, the clouds over Riau Province made the detection problems and there was no hot spot data (Fig. 6b). So when the clouds dissipated on 17 June 1998, there were only 160 hot spots detected (Fig. 6c).

On 14 June 1998, the vegetation fire areas in Riau and North Sumatra provinces were situated closely to the place of experiment on weather modification in Fraser's Hill (Fig. 2). Luckily, the artificial rain cloud went in the direction of the most intensive fires in Sumatra Riau province (Fig. 5). So this artificial rain cloud influenced the vegetation fire situation and reduced hot spot number 5.2 times (Sorokin 2000) within two days (Fig. 6). The weather modification over Malaysia (June–July 1998) and creation of artificial precipitations could also reduce the fire danger situation in Sumatra. The most effective tactics are not targeting the artificial rain in the vegetation fires area but reducing the Fire Danger Rating (FDR) by increasing the volume of artificial precipitations in the target area (Sorokin 2012b).

The forest fire extreme situation is very common to the USA in 2000 and to the Russian Federation in 2010. The special volume of Risk Excellence Notes (REN v. 2, num. 6, 2000) was devoted to the extensive monitoring during extreme fire situation at the Cerro Grande event near US Department of Energy (DOE) facilities Los Alamos National Laboratory in New Mexico and exploration of the fire at DOE's Hanford Site in the state of Washington. Unfortunately, the fire brigade with fire engine and fire aviation (helicopters and aeroplanes) was not very effective and could not stop the fire. The method of weather modification and creation of artificial precipitations can be helpful for struggling against forest fires (Sorokin 2000, 2011) and also effective for solving the problem of clearing the air from smog, haze and air ventilation (Sorokin 2012b).

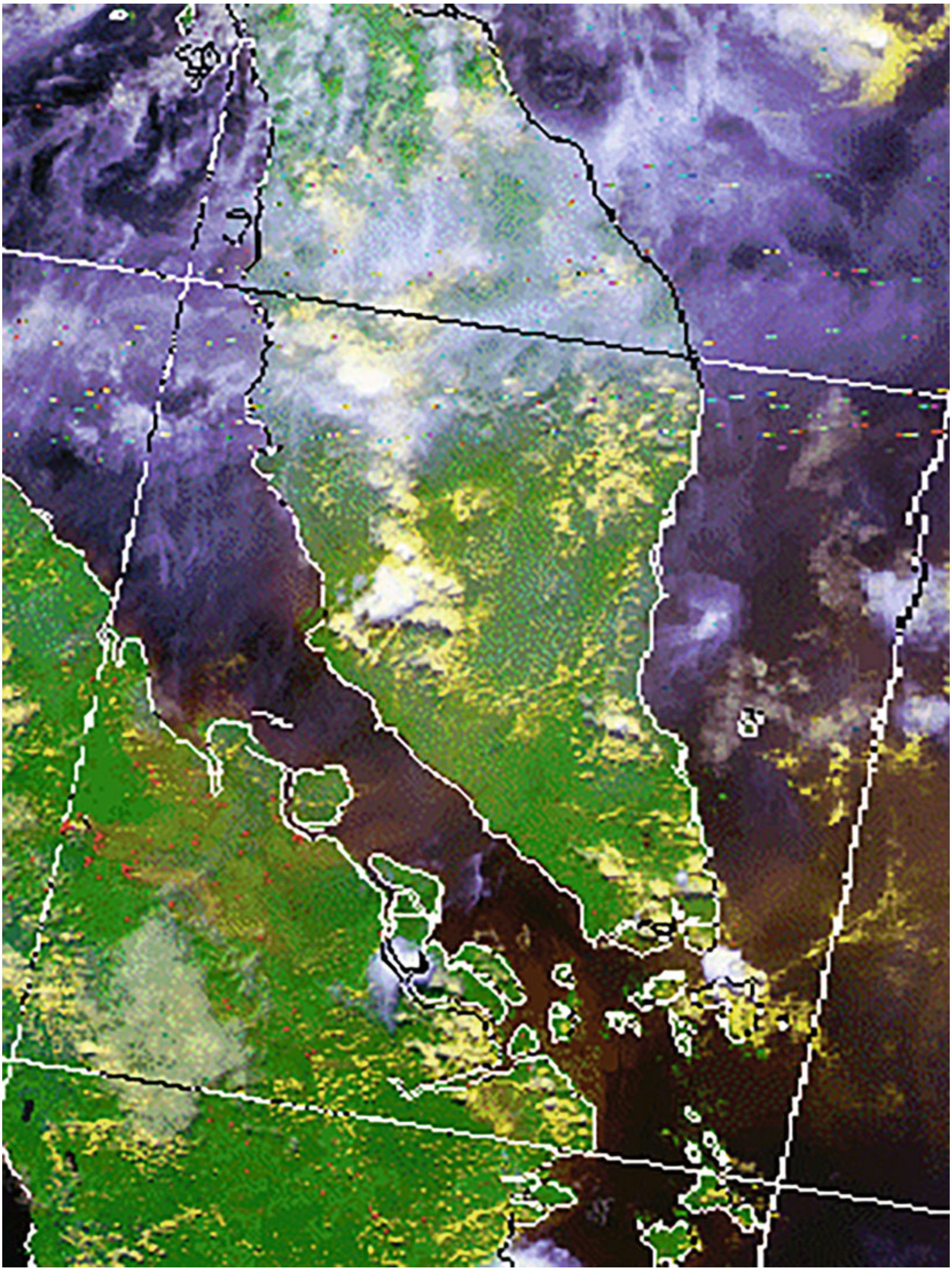

Fig. 2 Author modified image of the Composite image 08:03 GMT, 14 JUN 1998, Meteorological Service Singapore. *Source* Meteorological Service Singapore

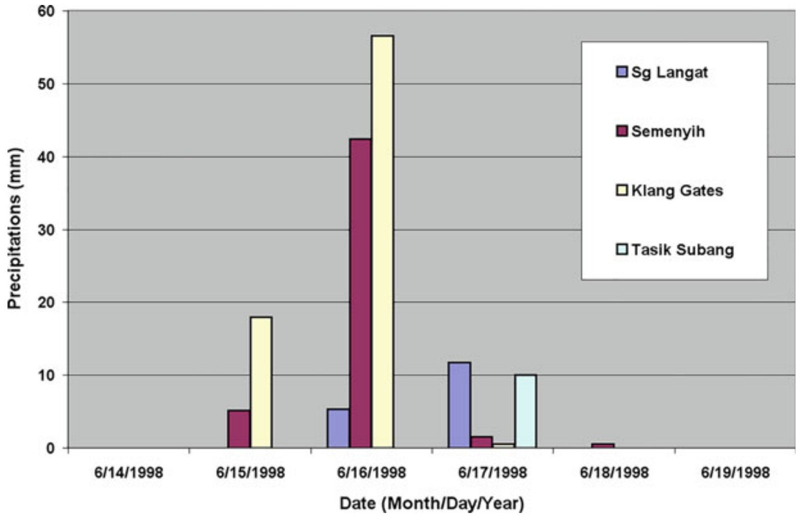

Fig. 3 Rainfall at the dam's catchment areas 14–19 June 1998. *Source* Author modified image, (Sorokin 2012b)

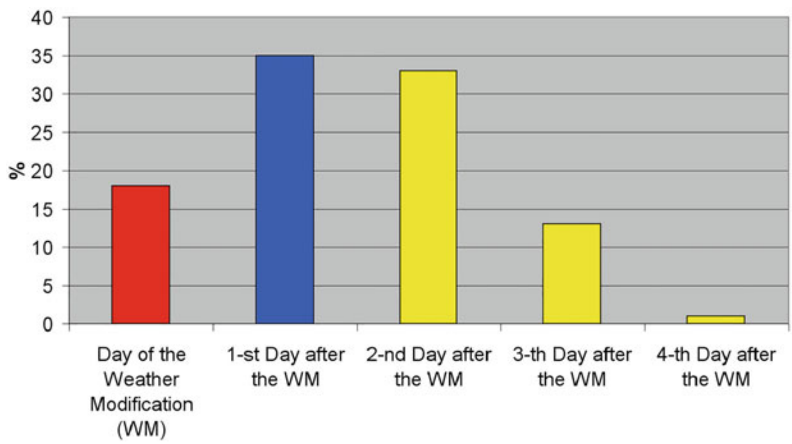

Fig. 4 Rainfall at the dam's catchment areas (%), 14 June–23 July 1998. *Source* Author modified image (Sorokin 2012b)

Results

The experiments on chemical free weather modification and creation of artificial precipitations during the extreme weather-related events are proved the high efficiency of this method. We create the artificial precipitations inside the anti-cyclone zone (Sorokin 2012b, c) in Moscow region, Russia. The chemical free weather modification increased more than two times the water production from dams (Sorokin 2012b) during the period of extreme drought (14 June–23 July 1998) in Malaysia. Artificial precipitations influenced the vegetation fire situation over Sumatra Riau province and reduced hot spot number 5.2 times within two days (Sorokin 2000).

Targeting artificial rain clouds in the dams' catchment areas can solve the problem of the town water supply during the drought (Sorokin 2000, 2012a, c). Targeting artificial rains in the agriculture regions can be also effective for minimization of drought sequences (Sorokin 2000, 2012a, c). Weather modification can be helpful for clearing the air from smog, haze and air ventilation of huge volumes. The method of chemical free weather modification and creation of artificial precipitations can be helpful for struggling against forest fires (Sorokin 2000,

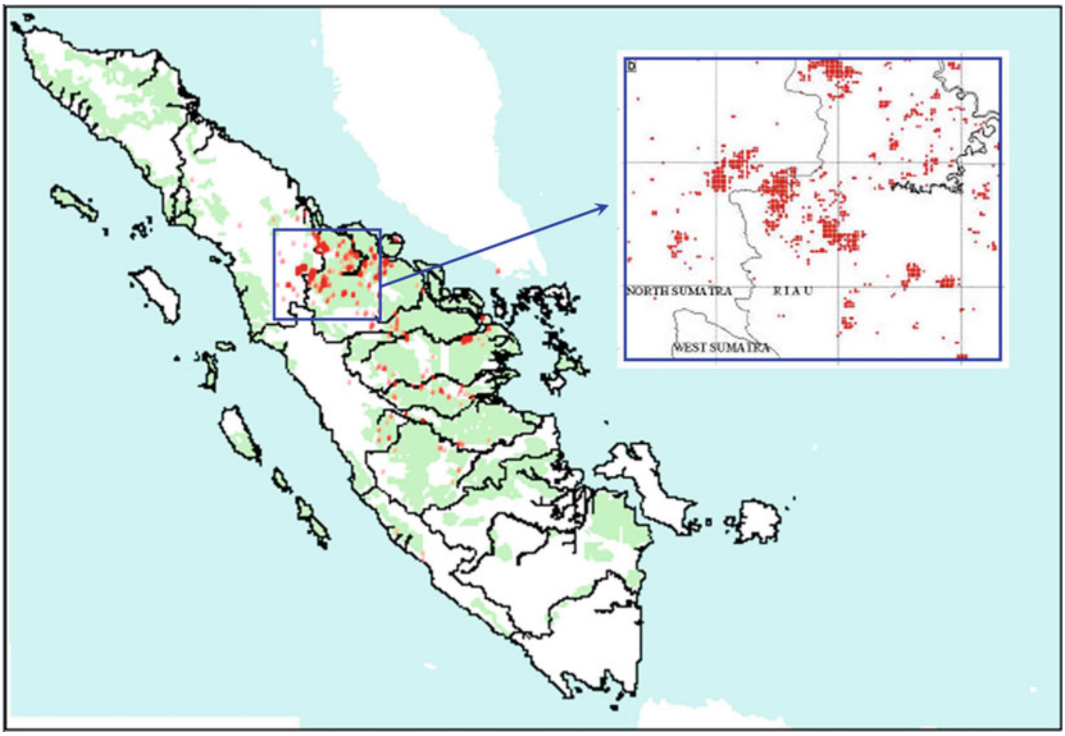

Fig. 5 Vegetation fire situation on Sumatra and Riau province, 14 June 1998. *Source* Author compilation of FFPCP data. Images produced by EU-Forest Fire Prevention and Control Project (FFPCP) (Anderson et al. 1999, 2000, Anderson 2001)

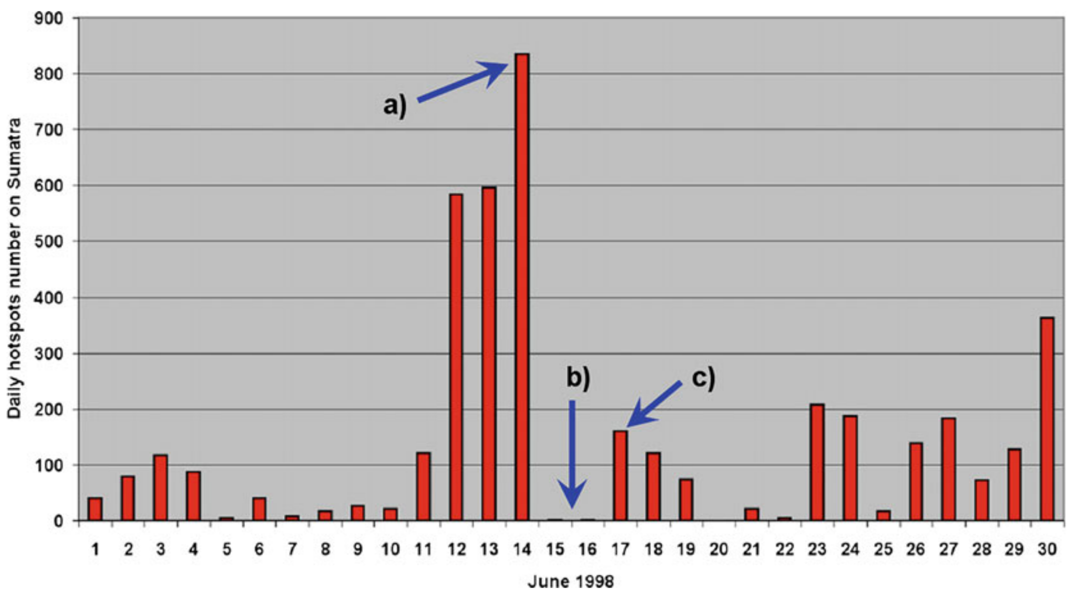

Fig. 6 Daily hot spots number on Sumatra (June 1998). *Source* Author compilation of FFPCP data

2011, 2012a, b) and also effective for solving the problem of clearing the air from smog and haze.

The economic losses from the extreme weather-related events (drought, vegetation fires and haze) can be significantly reduced in a number of times with the help of chemical free weather modification and creation of artificial precipitations. In the present time, the super-computer technology and advantages in the climate modelling give a hope on an up-to-date forecast of climate changes and extreme weather-related events. With the help of the climate modelling, it will be possible to estimate the economic losses from extreme weather-related events and the real efficiency from weather modification can be calculated.

The climate changes provide the global social, economic and political processes involving the groups of countries and the whole continents. As an example, the blocking anticyclone in Russia 2010 coursed the severe drought and forest fires in Russia and the flood in Europe. So the optimal solution for that time could be the redistributing the plenty water recourses from Europe to Russia and minimization of sequences from drought and flood. The basic idea for risk minimization and economic losses reduction from flooding is to move excess water to areas with water shortage (Sorokin 2012b, c). The main idea of risk minimization and reduction of economic losses from droughts is cutting the peak intensity and reduction of the event duration that will lead to a reduction of the event severity (Sorokin 2012a).

Discussion

The Sendai Framework for Disaster Risk Reduction 2015–2030 is aimed at action to prevent new and reduce existing disaster risks. The increasing of the global average temperature leads to the enlargement of the variation between the Minimum and Maximum temperature records. Global warming increased the number of Natural disaster events two times for past 10 years. Corresponding to them the disaster risks and economic losses are increasing. The economic efficiency of the method of chemical free weather modification during the extreme weather-related events is underestimated. The innovation methods of risk management with the help of modern technical solutions and chemical free weather modification can considerably reduce (in times) the economic losses from natural disasters (floods, droughts, forest fires).

The dams and big water reservoirs can be affected by earthquakes, and this is a very important threat for India. The biggest water reservoir in India is the highest (260 m) earth and rock-fill Tehri Dam. In the case of strong earthquake, this dam can be unstable and cause flooding. The main problem is the construction of the commercially efficient infrastructure including buildings and roads. The low cost constructions usually are not stable during strong earthquakes. In terms of geography, it is very important to create the maps all over India of the actual infrastructure seismic resistance, the population density, dams and dams' catchment areas, water supply, buildings and roads. So in the case of the Earthquake, the immediate assessment of the human and economic losses will be possible. This will helpful for the emergency operation planning. To reduce these losses in future, it is important to increase the requirements for seismic stability of constructions and replace the dangerous infrastructure.

It is very important to switch on active management of natural disasters. The main idea is to localize the threat before it will lead to catastrophic consequences and provide the effective solution to reduce damage, human and economic losses. This requires the development of mathematical models of crisis situations based on supercomputers; increasing the remote sensing system capabilities; creation ground-based emergency infrastructure and implementation of Disaster Risk management. Providing the detailed action plan for decision-makers and political makers can help them in taking the right solution.

The possible solution of Disaster Risk Reduction and minimization of economic losses from natural disaster is cutting the event peaks intensity, and reduction of the event duration that will lead to a reduction of the event severity (Sorokin 2012b).

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Sustainable Disaster Risk Reduction in Mountain Agriculture: Agroforestry Experiences in Kaule, Mid-Hills of Nepal

A. Schick, E. Wieners, N. Schwab and Udo Schickhoff

Abstract

Modernization as a transformational strategy towards sustainable development has to promote further improvement of mountain farmers' livelihoods while at the same time ensuring ecological sustainability and inducing social equity. In this context, a multiyear joint project with local farmers was launched in spring 2009 to introduce agroforestry practices in the village Kaule, Nuwakot District, mid-hills of Nepal. Practical components of the project included trainings and workshops on agroforestry, restructuring of terrace fields for conversion to agroforestry, and monthly meetings for open discussions among involved households. The project was accompanied scientifically to analyse socio-economic and ecological impacts. This paper presents scientific findings, summarizes the experiences during the transition to sustainable land management from an interdisciplinary perspective and gives evidence of increased willingness to adopt sustainable agricultural practices and the obtainment of environmental benefits and increased livelihood security. Participation of the farmers in the entire process, beginning with the definition of goals, the envisioning of a desired future and the integration of local knowledge, skills and resources were found to be of key importance for the project success. During the transition process, a diversification of marketable crops and additional income generation further enhanced the willingness to adopt new agricultural practices. After the adoption of agroforestry, soil quality and soil productivity have been significantly ameliorated, with

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positive effects appearing shortly after the conversion from conventional monocropping systems. We also assessed significantly higher species richness, beta diversity and cover of trees and shrubs in the agroforestry system. We conclude that the transition from conventional terrace cultivation to agroforestry practices has the potential to generate significant environmental and socio-economic benefits, thus contributing to sustainable modernization processes and disaster risk reduction in mountain agriculture.

Keywords
Agroforestry · Soil fertility · Sustainability · Modernization
Mountain agriculture · Innovation diffusion · Transition management
Backcasting

Introduction

In Nepal, the increased agricultural output as well as the extended variety and number of crops reflects a recent agricultural intensification process with an increasing commercialization of the still prevailing subsistence production system. The total production of agricultural commodities more or less steadily increased from 11.8 million metric tons in 1998/1999 to 18.9 million metric tons in 2010/2011, with a particularly high gain in cash crops such as potatoes, vegetables and fruits (CBS 2012). The adoption of agricultural inputs such as fertilizers, pesticides and hybrid seeds, and improved irrigation and road network systems essentially contributed to changes in cropping patterns, use of agrochemicals, irrigation and mechanization (Dahal et al. 2009; Raut et al. 2011). This agricultural intensification process threatens the sustainability of upland farming systems in the long run since it can have serious environmental consequences at various spatial scales—increased soil erosion, lower soil fertility and reduced biodiversity at the local scale, pollution of groundwater and eutrophication of rivers and lakes at the regional scale, and impacts on atmospheric constituents and climate at the global scale (Matson et al. 1997).

Since agricultural intensification continues to be a major threat to the provision of ecosystem goods and services and to sustainable development, a key development challenge is to implement land management and policy alternatives that ensure sustainable land use practices and simultaneously improve the livelihood security of poor and marginalized mountain dwellers. Any modernization efforts in the context of mountain agriculture in less-developed regions have to take this challenge into account. As an economic theory, rooted in capitalism, the concept of modernization incorporates the entire spectrum of a substantial transformation that a traditional agrarian society has to undergo to become a modern industrial society. Historically, this transformation commonly implied a process of disembedding of the growing industrial system from its social and natural context, contemporarily often perceived as a failure of modernization. Thus, the paradigm of sustainable development, emerging since the 1980s, can be construed as a concept aiming at re-embedding industrial activities into their social and natural context (Reid 1995; Huber 2000).

Modernization strategies seek to lessen vulnerability and to raise standards of living of the poor by disseminating information and knowledge about more efficient techniques of production. In the context of mountain agriculture, this process involves, for instance, persuading farmers to try new crops and shift to new production methods and marketing skills (Ellis and Biggs 2001). Thus, respective policies and strategies tend to be top-down in approach, and the modernization process does not necessarily lead to sustainable land use practices. Common concomitants of replacing traditional agricultural systems are the application of artificial fertilizers, herbicides and insecticides, the introduction of hybrids and genetically modified crops, and the general mechanization of crop cultivation.

Thus, if modernization and disaster risk reduction are understood as a transformational strategy towards sustainable development, it has to promote further improvement of mountain farmers' livelihoods while at the same time ensuring ecological sustainability and inducing social equity in terms of access to natural resources and sharing the wealth produced. The "reinvention" of agroforestry in recent decades has opened up an avenue which may lead to a modernization process which satisfies ecological as well as socio-economic needs of mountain-farming families. Commonly understood as an integrated approach of producing food, fodder, fuelwood and/or timber by combining trees and shrubs with crops on agricultural land, agroforestry has the potential to contribute to livelihood security and to provide additional benefits such as preventing hazards such as soil erosion, maintaining soil fertility, enhancing water quality, conserving biodiversity, and mitigation of climate change by carbon sequestration (Young 1997; Jose 2009; Nuberg et al. 2009; Powlson et al. 2011; Nair and Garrity 2012). In Nepal, agroforestry systems generally involve agricultural crops, tree crops and livestock (Amatya 1996) but have evolved from simple agriculture into a range of farming systems with varying degrees of integration (less integrated, semi-integrated and highly integrated agroforestry) including specific agroforestry practices such as home gardens, silvo-pastoral and forest-based systems (Amatya and Newman 1993; Dhakal et al. 2012).

In this paper, we analyse a transformation process in mountain agriculture using the adoption of agroforestry practices in a Nepali mountain village as a case study. A long-term joint project with local farmers was launched in Kaule, Nuwakot District, mid-hills of Nepal, in spring 2009 designed to introduce agroforestry as an approach to rebuild resilient rural environments and to ensure livelihood security (Schick 2015). This paper aims at providing an assessment of the effects of the adoption of agroforestry from an interdisciplinary point of view. We hypothesize that after several years of implementation and project activities, achievements along the pathway to sustainable modernization can be quantitatively and qualitatively evaluated by means of ecological, economic and social indicators. To test this hypothesis, we use data from household surveys, discussion groups, key informants from village institutions as well as from vegetation and soil-ecological field studies.

Materials and Methods

Study Area and Case Study Background

Kaule village (1860 m a.s.l.) is located on the upper slopes of the Kolpu Khola watershed in Nuwakot District (Fig. 1). The study area represents a typical mid-hill region of Nepal with respect to land management conditions. It has a subtropical monsoon climate with an annual precipitation of 2822 mm (recorded at the nearby climate station Kakani, 2064 m a.s.l.) (unpubl. data provided by the Department of Hydrology and Meteorology (DHM), Government of Nepal). In Nuwakot District, 69% of the economically active population is occupied in the primary sector. The mean farm size amounts to 0.59 ha with six head of livestock per household on average (Sharma 2010). In general, soil erosion, eluviation of nutrients and reshaping of terrace fields for the purpose of strawberry farming represent the major problems of land use in Kaule (cf. Bista et al. 2010). In Kaule, current agricultural land use comprises three agrosystems: (i) a mature, fully developed agroforestry system (AF), which was adopted on one land holding

15 years ago; (ii) the predominant conventional system (CS) is characterized by monocropping and a strong dependency on external inputs notably firewood, green fodder, fertilizer and pesticides. Farmers cultivate strawberries as cash crop, which is an important contribution to their income; (iii) a system that has been in transition to AF since 2009 (TS). The TS is located on land holdings of 15 families who have been participating in the agroforestry programme.

The instance that one farmer in the village has obviously successfully practiced agroforestry since 15 years was the reason to launch the long-term joint project with local farmers in 2009, initiated and still supported by the Nepalese–German NGO Kaule e.V. The AF farm served as a model farm for other farmers who decided to participate in the project. The goal of the agroforestry project was to establish alternative land management systems which reduce the risk of environmental degradation and enhance livelihood security. Moreover, the self-initiative of villagers should be encouraged in order to create a stable, long lasting, self-spreading and also in this way sustainable project. To respect cultural, religious and educational values and characteristics of project participants, trainers from Nepal were employed to provide lessons and training on agroforestry. The training included information about suitable plants for agroforestry, plant cultivation, nursery establishment and soil treatment as well as instructions for long-time farm development planning. To foster the self-expression of farmers and to grant them their own institutional identity, a legal association (Kaule Environment Nepal) was founded. Monthly meetings were organized to further support a group identity and to detect and discuss needs and wants of farmers. The first project phase (2009–2011) focused on agroforestry training and infrastructure as well as on group consolidation, whereas the second phase (2012–2015) is characterized by the transition to self-responsibility of the participating households.

Socio-Economic Data Sampling and Diffusion of Innovations Assessment

To better understand the dynamics within households and to learn about their role in project participation, the background of participating families has been analysed mainly by interviews. Structured, semi-structured and open interviews were conducted in English and Nepali with all participants on socio-economic and ecological issues. In order to understand the mechanisms and impacts of the introduction of agroforestry practices and to understand whether agroforestry in its complexity is suitable for a system change that can spread out and be adopted by other farmers, observed and documented events and data are evaluated against the background of the well-established theory of diffusion of innovations (Rogers 2003).

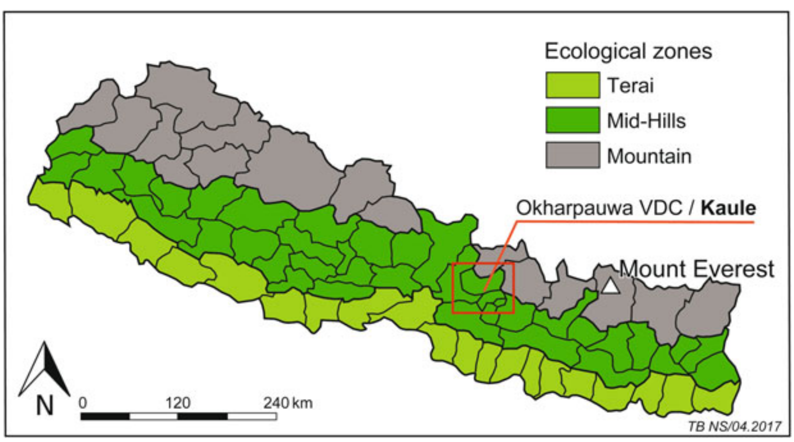


Fig. 1 Map of Nepal and study area

Table 1 Certain factors that can affect the diffusion process

Comprehensibility	Do project participants understand why the innovation is a solution? Do they understand the possible outcome?
Complexity	How many stages does the innovation involve?
Divisibility	Is partial adoption possible?
Risk	What are the consequences of failure?
Observability of success	How and when can success first be observed? How long are the stages between input and output?
Observability of failure	How is failure visible?
Compatibility	Does the innovation match existing cultural practices and norms?
Labour input	What implications has the innovation on labour input?
Costs	What are the short-term and long-term costs?
Return	What are the benefits of the innovation?

Table 1 illustrates several propulsive or inhibiting factors that account for the diffusion of an innovation and determine its speed. In order to estimate the diffusion potential of agroforestry in Kaule, interview data were analysed in the light of these factors.

Transition Management/Backcasting

Transition management is a systems approach which aims to manage and foster transitions from one status quo of a system towards another (Loorbach and Rotmans 2006). This transition from one stage to another should be accompanied and managed in a way that the next stage is a more sustainable one. Transition management is a circular process with no real end and beginning, as experiments, learning and adjustment are core elements. A transition agenda is defined which compromises the topics to be discussed as well as the stakeholders to be included and finally leads to strategic planning and the design of development paths (Loorbach 2010). Backcasting is one instrument from the field of transition management. It has been developed in Europe mainly in the context of energy, transport and wastewater management (Peake 1994; Wiederkehr et al. 2004; Gleeson et al. 2012). It comprises the elaboration of common future visions in the far future with all stakeholders concerned and the preparation of pathways to achieve this future vision. Responsibilities are assigned and tasks distributed to ensure the implementation of the future vision (Carlsson-Kanyama et al. 2008). Transition management and backcasting have been developed in Europe. There is a huge potential though for their implementation in less-developed countries in the context of development cooperation projects, as they encompass a new dimension of participation. Data for the backcasting and transition management study were collected in a time span of 2.5 years from 2012 to 2015.

After a thorough system and actor analysis, three workshops with different focus groups (women, men and “leaders”) were conducted in May 2014. During these workshops, participative cartography, sorting of cards, sorting of pictures and other methods were used to get people to open up and to share their visions for the future and their perceptions of the current situation. We considered participation in all stages of project planning and implementation as crucially important since it has been identified as a key element for creating ownership feeling for projects among participants and thus project success (Bamberger 1991).

Soil and Vegetation Data Sampling

In order to quantify and assess effects of the transition to agroforestry practices, we comparatively analysed soil properties in the three agrosystems (AF, CS and TS) described above (see also Schwab et al. 2015). The small-scale pattern of AF, CS and TS that exists in Kaule after the introduction of agroforestry made comparative studies on the spatio-temporal development of soil properties possible. Soils of AF, CS and TS fields could be sampled within a small area (0.5 km^2) in a narrow altitudinal belt. Thus, we minimized variations in bedrock or other abiotic or biotic factors which might influence soil properties except cultivation practices. Moreover, we analysed samples from not intentionally managed terrace risers in immediate vicinity of the sampled fields as uncultivated controls.

We determined tree and shrub species (nomenclature according to eFloras 2008), counted individuals and estimated tree and shrub cover of eight randomly selected mid-sized terraces within each agrosystem (AF, CS, TS; 24 terraces in total). Additionally, we estimated total vegetation cover of the terrace risers as these steep parts are particularly exposed to erosion, especially during the rainy season. The three agrosystems' mean values of vegetation cover were tested for significant differences by H-test (non-normally distributed values). All computations were carried out using "stats" R functions (version 3.1.2; R Core Team 2014) and the package "pgirmess" (Giraudoux 2015) and a modified code of the package "gplots" (Warnes et al. 2014) for the construction of boxplots.

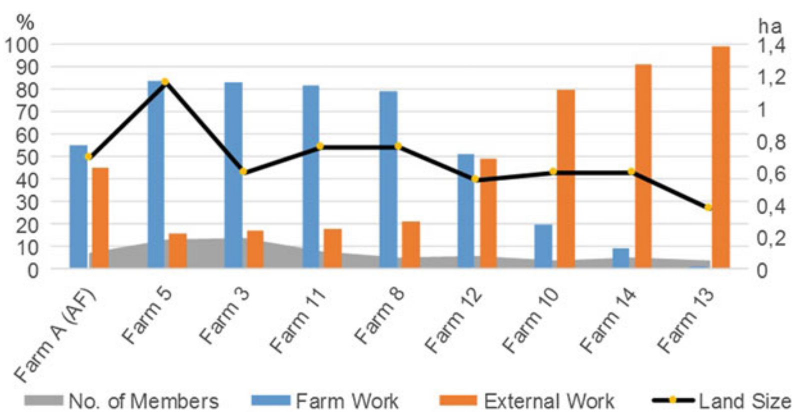
Results and Discussion

Livelihood Generation

Linkages between land size, family size and income generation strategies are depicted in Fig. 2. Income is generated either with external work or with products of the own farm. In most cases, bigger family sizes are connected to bigger land sizes and to farm work as an income strategy. Farms are frequently enlarged by including land from various family members instead of splitting land in order to create larger farmland units. More land for farming also allows intersecting farm strategies. For example, the integration of strawberries or other cash crops into subsistence farming needs in many cases extended land areas for cultivation.

Apart from the well-established agroforestry farm (farm A), eight farms out of fifteen were ready to provide data on their income. Compared to the evaluated transition farms, the long-established agroforestry farm A has a fairly balanced income strategy between farm work and external work, combined with a rather small

Fig. 2 Overview of income source, number of family members and land size



land portion. Since diverse rural livelihoods are less vulnerable than undiversified ones, diversification has positive attributes for livelihood security (Ellis 2000). Household income of farm A is based on two pillars. If one income source temporarily decreases, the other source can outweigh the financial loss. For households with smaller land sizes that do not want to unite to larger family structures, agroforestry might be a good option as it allows to produce food and income on smaller land sizes by using the given space more effectively.

At project start, the participating families decided how much land they were ready to set aside for the transformation into agroforestry. The smallest percentage of transformation land was 3% while the biggest percentage of transformation was 57% of total land per family (Fig. 3). The huge difference in land allocated for transformation is remarkable. The individual decision might be based on different factors including personal trust in the project or available marginal land (or other land) for transformation. In general, households with smaller land sizes provided higher percentages of their total land for transition. The fact that households with smaller land size wanted to transform larger land portions might be connected to their wish to diversify their income generating strategies and follow the given example of the well-established agroforestry farm.

Diffusion of Innovations Assessment

The diffusion of innovations theory (Rogers 2003) explains the reasons for adoption and rate of diffusion of new ideas and technologies (innovations) within a community. Hoffmann et al. (2009) later pointed out the importance of a situation-specific approach in this context, in order to adjust the concept to unique situational settings of individual projects. The decision for adopting an innovation depends strongly on the constellation of the surrounding force field, derived from the subjective perceptions of potential adopters. Force fields can be produced within groups, for example by social behaviour codes or expectations, or externally by political developments or environmental events (Elsass and Veiga 1994; Henrich 2001; Swanson and Creed 2014). Changes of the force field through the interactions of group participants and changes of external circumstances may influence the process of diffusion.

The introduction of agroforestry in Kaule is seen as an innovation, even though one farmer has been practicing agroforestry since several years. The beginning of the diffusion process is determined when other farmers adopt the innovation. In Kaule, the adoption was initialized when training and materials were provided by the agroforestry project.

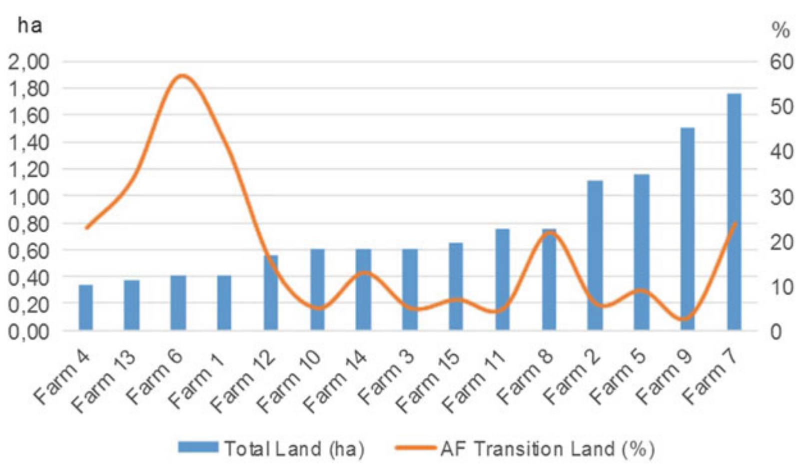


Fig. 3 Total land in hectares and percentage of transition land per household

In the following, we summarize the results of interviews and field observations with regard to the potential of agroforestry for adoption and diffusion (cf. Table 1):

Comprehensibility About 100% of all 15 interviewed households stated that they would like to establish a farm like the existing agroforestry farm. This farm is a visible example and serves as a model farm for potential adopters that allow to perceive the possible advantages of agroforestry (Albrecht 1964; Thomson and Bahhady1995). (+)

Complexity Agroforestry includes many plant species and varied techniques. It is extremely complex (Smith et al. 2012) and needs several years for full establishment. For this reason, it might be hard for farmers to follow their accustomed lifestyle and build up a new agrosystem at the same time. But as soon as farmers are able to derive some income through a newly introduced plant or technique, other farmers also get positively interested (cf. Conning and Udry 2007) as we observed in Kaule with the introduction of lemon grass and kiwi. (∓)

Divisibility All participants only provide part of their land for transition to agroforestry. The risk to lose the total livelihood subsistence was therefore minimized. It is not important that all farmers adopt all plants and suggested techniques at once. Each single introduction can be applied separately and more can be added over time. In 2009 and 2010, 31 different kind of plants were distributed to all participating households. Table 2 illustrates the survival rates until 2012. (+)

Risk Shortly after the project start, many of the plants distributed to the farms did not survive (cf. Table 2). This generated criticism among other villagers that did not participate in the project. For them, it was not comprehensible why so many fodder plants were distributed and cultivated (for details see Table 3). In the case that some of the new techniques fail, there is the possibility of a loss of credibility for the agroforestry system on the whole (Cash et al. 2003). (−)

Observability of success The well-established agroforestry farmer is nowadays, after at least 10 years of input, a successful and respected person in the village. All interviewed farmers stated that they would like to have a similar agroforestry farm.

A first visible sign of success for all is planting and thriving of plants on the fields (cf. Table 2). The next step is increasing financial income by selling harvested agroforestry fruits as it happens nowadays with lemongrass tea. The improved facilities of farms through investments represent the last observable stage in case of success. (+)

Observability of failure Some introduced plants were unknown to farmers and they did not know how to use or cook them. In addition, they could not estimate the value of such plants. This was an impeding fact, for example, for the introduction of *asparagus*. All plants died after being newly introduced. (−)

Compatibility The AF system seemed to be compatible with cultural and traditional practices in Kaule. Sunwar et al. (2006) describe that home gardens are a traditional agroforestry practice in Nepal. But agroforestry is not compatible with all of the varied strategies of livelihood generation. Immink and Alarcon (1993) stress that it will only be adopted if on-farm work is significant for the household income and generates an important source of income for the foreseeable future. Until 2014, six farms had a visibly positive development of agroforestry plants on their land. Five farms left the project, while four farms still participated formally in the project but had limited success in plant cultivation. (∓)

Labour input To establish an agroforestry system is a labour-intensive process. However, the established agroforestry farm household reported that once the agroforestry system is running, labour input can be seen as being reduced in terms of time load because farmers can produce resources they need on their own and do not need to spend as much time as before to collect wood, fodder or food outside their farm. (∓)

Table 2 Survival percentage of total plant species and individual plants from 2009 to 2012

	Species survival %	Plant survival %
Farm A (Agroforestry)	88	67
Farm 3	88	25
Farm 10	83	14
Farm 15	75	30
Farm 2	74	25
Farm 11	74	17
Farm 5	70	15
Farm 4	65	7
Farm 14	64	10
Farm 12	52	7
Farm 13	50	12
Farm 8	45	8
Farm 6	43	12
Farm 9	26	2
Farm 1	0	0
Farm 7	0	0

Costs Even if no external financial support is provided, the costs for plants and seeds are affordable. Farmers can theoretically cover such costs with loans. Out of eight households that provided data on income and expenses, two took a loan in 2010. The locally established AF committee applies regularly for funding from governmental or non-governmental organizations within Nepal to facilitate its members with trainings and materials. Once the cash crops of the agroforestry project start to generate income, adopters can reinvest in further techniques. (+)

Return Agroforestry offers a wide range of income generation. Fruits, vegetables and cash crops (cf. Table 3) enhance marketing options. The existing AF farm gained 36% of the total annual income with the harvest of wood. Agroforestry and affiliated practices might also add to a more diverse diet of adopters. (+)

After reviewing positive (+) and negative (−) aspects of the adoption of agroforestry in terms of its potential for diffusion, it becomes obvious that it is a very appropriate innovation with a great potential to spread throughout a village community like in Kaule. We estimate its capability for enhancing livelihood security as rather high, but we are also aware of potentially severe intricacies during the adoption process.

Transition Management/Backcasting

In three focus group workshops (females, males and leaders), the current situation was defined and discussed and future visions were worked out. As obvious from Table 4, the perceptions of the female and male farmers about their desired future situations deviated to some extent: While men considered improved markets and roads a prime target, women prioritized enhanced education and the unity of the community. In addition, the group of leaders highlighted still other issues.

The farmers have a very holistic view of their livelihoods and they see everything as interconnected. Their clear focus is on agriculture, as this is their main source of income. The leaders had somewhat different perceptions and ideas of the main development paths for the village. This gap

Table 3 Distributed plants and seeds in 2009 and 2010 in Kaule

#	Nepali name	English name	Scientific name	Use	Area	No. of plants per family	Distribution
I.	*Non Timber Forest Products (NTFPs)*						
1.	Amriso	Broom Grass	*Thysanolena maxima*	broom	corner edge	5	Mar. 2009
2.	Lemon Grass	Lemon Grass	*Cymbopogon citratus*	tea, spice cash crop	riserslope	10	Mar. 2009
3.	Tejpata	Cinnamon Leaf	*Cinnamomum tamala*	spice	corner	2	Mar. 2009
4.	Timbur	Nepal Pepper	*Zanthoxylum armatum*	spice medicine	corner	1	Mar. 2009
II.	*Fodder Plants*						
5.	Bakaino	China-Berry	*Melia azederach*	fuel wood pesticide	edge	seed	Apr. 2009
6	Bhatmase	Soya Bean	*Glycine max (L.) Merr.*	fodder green manure	edge riser slope	seed	Mar. 2009
7	Epil Epil	White Leadtree	*Leucaena leucocephala*	fuel wood foddergreen manure	edge riser slope	seed	Mar. 2009
8	Mendola	Notavailable	*Tephrosia candida*	hedge-rownitrogen fixation	edge	seed	May 2009
9	Nimaro	GiantIndian Fig	*Ficus auriculata*	livestock fodder	edge riser slope	seed	May 2009
10.	Rai Khanayo	Nepal Fodder Fig	*Ficus semicordata*	fuel wood fodder	corner	seed	Mar. 2009
11.	Siris	Women'sTongue Tree	*Albizia lebbek*	erosion resistant nitrogen fixation	edge corner	seed	Mar. 2009
12.	Tanki	Butterfly Tree	*Bauhinia purpurea*	fuel wood fodder green manure	edge riser slope	seed	Apr. 2009
13.	Badame	Peanut	*Arachis hypogaea*	livestock fodder	edge riser slope	seed	May 2009
14.	Molasses	Melinies Grass	*Melinis minutifolia*	livestock fodder	edge riser slope	seed	May 2009
15.	NB21	Napier Grass	*Pennisetum purpureum*	livestock fodder	edge riser slope	seed	May 2009
III.	*Vegetables*						
16.	Farshi	Pumpkin	*Curcurbita pepo*	vegetable	plain	seed	Mar. 2009
17.	Kankro	Cucumber	*Cucumis sativus*	vegetable	plain	seed	Mar. 2009
18.	Khursani	Chilli	*Capsicum annuum*	vegetable	plain	seed	Mar. 2009
19.	Kurilo	Garden Asparagus	*Asparagus officinalis*	vegetable cash crop	plain	60	July 2009

(continued)

Table 3 (continued)

#	Nepali name	English name	Scientific name	Use	Area	No. of plants per family	Distribution
20.	Rahari	Pigeon Pea	*Cajanus cajan*	vegetable fodder	edge	seed	May 2009
21.	Simi	Lablab	*Dolichos lablab*	vegetable	plain	seed	Mar. 2009
22.	Tamatar	Tomato	*Lycopersicon esculentum*	vegetable	plain	seed	Mar. 2009
IV.	*FruitTrees*						
23.	Amba	Guava	*Psidium gaujava*	fruit	plain	2	July 2009
24.	Anar	Pome-granate	*Punica granatum*	fruit	plain	2	Aug. 2010
25.	Avocardo	Avocardo	*Persea americana*	fruit	plain	5	Aug. 2010
26.	Kaagati	Lime	*Citrus aurantifolia*	fruitpickles	plain	5	July 2009
27.	Kera	Banana	*Musa paradisiaca*	fruit	plain	1	May 2009
28.	Kubi	Kiwi	*Actinidia deliciosa*	fruitcash crop	plain	3	Aug. 2010
29.	Lapsi	Nepali Hog Plum	*Choerospondias axillaris*	fruitpickles	plain	seed	Mar. 2009
30.	Litchi	Lychee	*Litchi chinensis*	fruit	plain	2	Aug. 2010
31.	Nibuwa	Lemon	*Citrus limon*	fruit pickles	plain	2	Aug. 2010

Table 4 Perceptions from three focus groups how the village should look like in 5 years

Women	Men	"Leaders"
In 5 years…	**In 5 years…**	**In 5 years…**
… there should be a good trash management	… there is no more trash on the road	… agricultural production is organic everywhere
… every person (especially women) should be educated	… there is more forest	… there is a proper irrigation system
… there should be more trees	… there are more fruit trees	… every house has a trash management system
… there should be more (different, new) crops	… there are new crops/fruits	… every house has a toilet
… everybody should work in UNITY	… there are better employment options	… there is good livestock management
… everybody should have a job	… every house has a toilet	… there is access to abroad markets
… every house has a toilet	… there is a better water management	… the village of Kaule has a market stall in KTM
… there is should be a good water management	… there is a good road	… all people are educated
	… there is a good market for products	… everybody receives/received adult education
		… there will be more trees
		… there will be a temple
		… there will be no more drinking/alcohol problem
		… tourism will be promoted and homestays will be possible in the village
		… there will be a store room/cold room for the agricultural products
		… there is a building for community meetings and gatherings

can be explained by the different education levels of the participants, as most of the farmers did not finish primary school while the leaders had attended college. Furthermore, some of them are not from the village itself and thus have no in-depth local knowledge which leads to a different assessment of the villages' situation. This perception gap can become very problematic when the people incharge do not sufficiently consult with the farmers before making decisions (Wieners et al. 2015a, b).

Taking the elaborated desired future transitions into account, it becomes obvious that an agricultural system such as agroforestry would incorporate the main envisioned changes (more trees, more fruit trees, more new crops, better water management, new markets) and thus brings about the requirements to be promoted in the village in the form of a project. Though some adaptations have to be made to implement backcasting in a country like Nepal, it seems to be an adequate instrument to foster project ownership feelings and participation (Wieners et al. 2015a, b).

Soil Quality, Vegetation Cover and Species Richness

Pronounced differences in cultivation practices between the AF farm and the CS farms in Kaule have resulted in significantly deviating soil properties (see also Schwab et al. 2015). The AF soil provides distinctly more favourable growth conditions in terms of soil chemical parameters after 15 years of AF management.

We found a significant difference between the pH of the AF field soils (median pH 4.83) and the CS field soils (median pH 4.30). Likewise, Al^{3+} and Fe^{3+} contents of the AF field soils are very low: all AF samples contain less than 0.32 cmolc/kg Al^{3+} while the CS field soils' median is 1.02 cmolc/kg Al^{3+}. The AF samples' average iron content shows 8.58 mmolc/kg Fe^{3+} while it is 43.08 mmolc/kg Fe^{3+} in the CS. In consequence, AF field soils have a much higher base saturation (median 97 vs. 67%, respectively). Organic matter content (2.19 vs. 1.55%) and total nitrogen content (0.13 vs. 0.10%) are much higher in the AF field soils. The same holds for effective cation exchange capacity (3.9 vs. 3.1 cmolc/kg) and for phosphorus content (73.8 vs. 48.2 mg/kg). In contrast, the terrace riser soils did not show any significant differences across the systems. Thus, the contrasting soil quality had to be largely attributed to the differing land management practices. No mineral fertilizer has been applied in the AF system; it exhibited improved compost composition and higher abundance of nitrogen fixing legume tree species (Fabaceae). The differences in cultivation practice enhanced soil quality and long-term soil productivity, as it was also found in other studies (Young 1997; Fageria 2012; Lamichhane 2013; Ghimire and Bista 2016). Several TS soil parameters already exhibited a convergence towards the AF values after two years of transition only. Thus, the transition to AF positively influenced soil properties shortly after the conversion from conventional monocropping systems, resulting in potentially higher yields.

We found in total 34 tree and shrub species in the AF, 16 in the CS and 37 in the TS. The differences in species richness were significant ($p < 0.05$) for the CS in comparison to AF and TS. Likewise, the number of tree and shrub individuals varied among the agrosystems: The medians of the abundances were 22.5 for the AF, 11.5 for the CS and 32 for the TS. In total, we found five nitrogen-fixing species in the AF and TS each while there was only one in the CS. There were also more fodder tree species (by definition of Panday 1982) in the AF (11) and TS (12) compared to the CS (6).

The tree and shrub layers covered the AF terraces by 22%, the CS terraces by 7% and the TS terraces by 11% (mean values). About 93% of the terrace risers of the AF were covered by vegetation. Thus, they were significantly ($p < 0.05$) better protected from splash erosion than terrace risers of the CS with a vegetation cover of only 62%. None of the AF terrace risers was covered less than 80% (TS minimum: 75%) while the median was at 70% coverage with a minimum of 20% in the CS. After 2 years of transition, the TS vegetation cover of the terrace risers already reached a mean of 87% and did not differ significantly from the AF cover values (Fig. 4).

Species richness in our study area was within the range of other studies in the mid-hills of Nepal (Panday 1982; Gilmour 1989; Kollmair 1999; Acharya 2006; Sharma and Vetaas 2015).

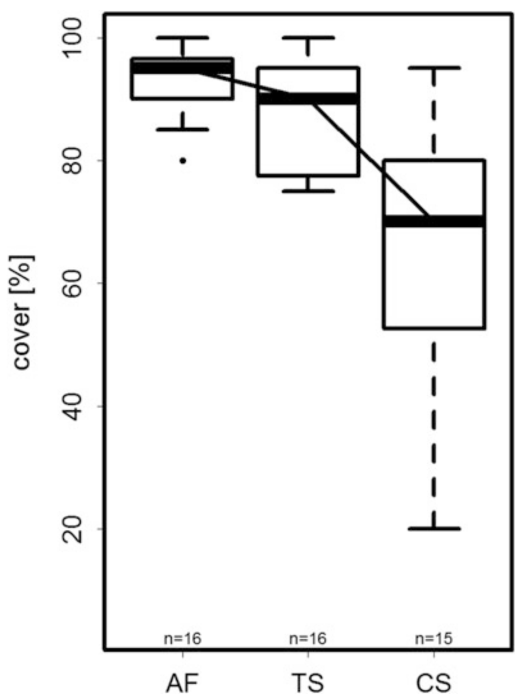


Fig. 4 Vegetation cover of the terrace risers. *AF* agroforestry, *TS* fields in transition process, *CS* conventional system

Differences in species numbers between AF and CS indicate a higher tree and shrub diversity of the AF. Considering that the Nepalese agrobiodiversity is threatened and that the mid-hills are not sufficiently represented in the protected areas of Nepal (Upreti and Upreti 2002; Shrestha et al. 2010), AF practices may efficiently contribute to in situ conservation of species. Moreover, increased species richness diversifies food options of the farmers and improves their self-sufficiency and food security (Bardsley 2003; Gautam et al. 2009). Although AF practices reduce negative impacts of land use by integrating biodiversity and agriculture, they are currently rather neglected by Nepalese biodiversity policy instruments (Sharma and Vetaas 2015).

Vegetation cover plays a considerable role in protecting soil from erosion. The higher vegetation covers of AF and TS point to substantially smaller erosion risks in the transformed agrosystem. This applies especially for splash erosion during heavy rainfalls of the rainy season which generate a large proportion of annual runoff (Gardner and Gerrard 2003; Merz et al. 2006). Reduced erosion contributes to the more fertile soil status of the AF and TS systems.

Conclusion

The adoption of agroforestry practices brings about varied socio-economic and ecological benefits that not only reaches the adopters but are disseminated to the society as a whole. Agroforestry offers a pathway to sustainable modernization and disaster risk reduction of mountain agriculture by providing extra income, generating employment, leading to improved food and nutritional security and reversing the deterioration of the environment. If the agroforestry project in Kaule is successful in the long run, it will help local farmers to better cope with economic and environmental risks such as the recent earthquake disaster by reduced landslide risk and better food supply, and potentially in terms of financial security if increased income through agroforestry leads to decreasing dependence on migrant remittances. Participation of people in all stages of project planning and implementation is of key importance for project success, as it creates identification with the project and ensures that local knowledge is incorporated.

Backcasting and transition management seem to be adequate methodologies to design development paths towards sustainable cultivation systems and livelihoods, as the process incorporates scientific as well as local knowledge and might bridge the often felt gap between local farmers and project and government agencies. However, backcasting might not be a kind of panacea for enhancing long-term development projects. In similar project settings, rather a combination of an analytical diffusion of innovations assessment combined with the bottom-up technique of backcasting might be a promising approach.

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Building Community Resilience to Flash Floods: Lessons Learnt from a Case Study in the Valles Urban Area, SLP, Mexico

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Abstract

Floods are frequent events in Mexico that often lead to economic losses. Nonetheless, learning from these effects after such disasters that lead to improved preparedness and community resilience is limited. This paper analyzes the Magisterial community building resilience to flash floods. Based on Liao theoretical approach about the key properties of resilience, a survey was carried out based on household questionnaires and expert interviews in the selected study area. The analysis of building resilience community allowed the identification of strategies used to cope with flash floods and identify the aspects that have favored or inhibited the construction of resilience. In order to cope with flash floods, the community has promoted strategies independent of those carried out by the local government, but these do not have a significant contribution to resilience. Based on the results, it is established that the Magisterial community, although organized on its own initiative and having made adjustments through the implementation of strategies to cope with flash floods, is not a resilient community. However, fundamental aspects for the construction of resilience have been developed. A radical change in Mexico's flood risk management paradigm is required to promote resilience at all governance and decision-making levels.

Keywords

Community resilience · Disaster risk reduction · Flash floods
Ciudad Valles-SLP

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Introduction

At a global level, exposure and vulnerability to flooding is high and the disasters associated with this hazard lead to greater economic and social losses. About 250 million people are affected each year, costing 90 billion USD and by 2030 this could exceed 500 billion USD (WRI 2015). In Mexico, about 62% of the population lives in areas where flooding occurs on a regular basis (CONAGUA 2012). Flood-related disasters are the most recurrent disaster (INE 2012) and cause high losses. For the period of 1943–2004, these losses are estimated to have been 5525 million USD (CENAPRED 2007). Meanwhile, 48.5% of the cost of post-disaster reconstruction corresponded to excess rainfall/flooding in the period of 2000–2011 (FONDEN 2012).

In the face of this scenario, strategies such as the Sustainability Development Goals (UN 2015), the Framework Disaster Risk Reduction 2015–2030 (UNISDR 2015), and Resilient Cities (UN 2014) have recently emerged emphasizing the importance of building resilience and the key role it plays in risk reduction.

Resilience is defined as "the ability of a system, community, or society exposed to hazards to resist, absorb, accommodate, transform, and recover from the effects of a hazard in a timely and efficient manner, including through the preservation and restoration of its essential basic structures and function through risk management" (UNISDR 2009). In this context, it is necessary to consider the complexity of resilience and the lack of a practical interpretation for its application in risk management (Garschagen 2011; De Bruijn 2004), despite the operational definitions established by international bodies.

Although the importance of building resilience in communities is common among the various actors involved in risk management, research on aspects that favor or inhibit resilience are scarce and more research is needed to document and analyze the knowledge within these communities which are directly affected by disasters (Thornley et al. 2015). In this sense, work on the construction of community resilience could contribute to the redefinition of concepts and identification of fundamental aspects for its construction, recurrent factors that inhibit its construction, and necessary or essential synergies between actors in the various scales of risk management and in general to develop a better understanding of the subject.

Considering the above, this paper examines the construction of resilience within the community of Magisterial neighborhood, located in the Valles Urban Area (VUA) in the State of San Luis Potosí, Mexico (Fig. 1). In July 2008, this community experienced a flash flood for the second time. The flood affected many neighborhoods of the VUA and the capacities of local and state government were exceeded and so, in order to face the emergency and recovery, support and economic resources from the National Fund for Natural Disasters (FONDEN) were requested. After the emergency, unlike other neighborhoods, the residents of Magisterial neighborhood, on their own initiative, began to organize themselves to take actions in an attempt to reduce the impact of floods (Valadez-Araiza 2011).

The objective of this work is to analyze the construction of community resilience to flash floods, adapting the theoretical approach of Liao (2012), based on the identification of coping capacities at the household, community, and local government levels in the various phases of risk management, by obtaining qualitative data and using a deductive approach to a case study.

Definitions and Methods

Studies on community resilience and its measurement face challenges such as the definition of concepts, the difficulty of assessing the changing socio-natural dimensions of resilience over time, and the development of indicators to map resilience and its dimensions consistently (Twigger-Ross et al. 2014). On the other hand, resilience approaches should focus on understanding what the community does on its own to respond to changes (Twigg 2007), i.e., their ability to make use of their available capabilities and resources to cope with disasters.

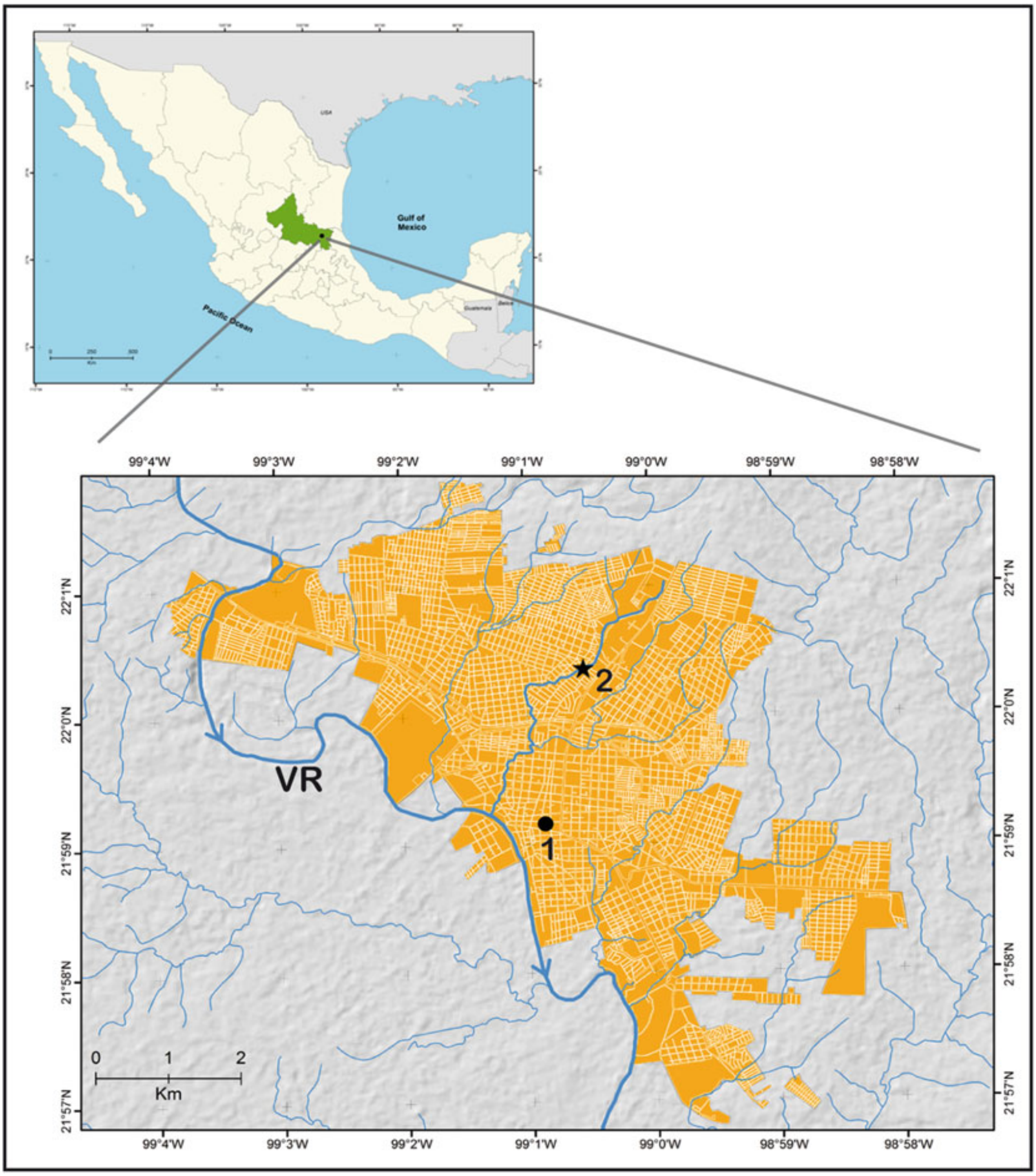

Fig. 1 Location of the study area in Valles urban area, San Luis Potosí State, Mexico. (1) Downtown Valles. (2) Magisterial neighborhood. *VR* Valles River

Resilience as defined above is a concept that implies the prior exposure of a vulnerable community to a threat, so vulnerability itself is embedded in the concept of resilience (Lei et al. 2013) and forms part of it (Turner et al. 2003; Zhou et al. 2009; Birkman 2006).

Resilience is recognized as a dynamic condition of vulnerability and involves a dynamic community response to survive and recover from the impact of a threat (Mitchell and Harris 2012) in terms of response capacity (Gallopin 2006; Birkman 2006; Smith and Wandel 2006;

Turner et al. 2003; Lorenz 2013). Response or coping capacity is "the ability of people, organizations, and systems, using available skills and resources, to face and manage adverse conditions, emergencies, or disasters" (UNISDR 2009); thus responses to a threat reflect a community's ability to resist, absorb, accommodate, transform, and recover from the effects of a hazard.

Liao (2012) points out that flood resilience is the ability to prevent physical damage, socioeconomic disruption, and the ability to reorganize and that it depends on three key properties: the ability of the system to organize itself and take action to cope with floods independently of localized flood response capacity; the ability to learn from each flood event and based on the understanding of the new phenomenon, make timely adjustments and; the diversity and replication of measures or strategies in risk management at the organizational levels immediate to the community (redundancy at subsystems) in a way in which they support each other in case an organization level is exceeded. For the development of resilience, diversity and flexibility or openness to different and innovative options are indispensable conditions.

The concept of community has been used to study resilience based on the abilities and skills of a group of individuals (Edwards 2009) who share the same concerns (Price-Robertson and Knight 2012) and live in the same geographical area under risk (Twigg 2007). In this study, we refer to the Magisterial community as a geographic-administrative entity made up of houses, urban equipment, and inhabitants, who have in common an exposure and vulnerability to flooding.

The flash floods are turbulent behavior caused by torrential runoff that often causes flooding. Although they are typical of semiarid and arid areas (Moore et al. 2005), their occurrence is more frequent in tropical and temperate urban areas where patterns of runoff, infiltration, and evapotranspiration have been altered by human actions.

In the present work, the construction of community-level resilience to flash floods was done by analyzing the key properties of resilience (Liao 2012), based on copy responses at the household, community, and local government levels and the various phases of risk management (in, post- and pre-phases). A qualitative approach was used to analyze resilience, based on a case study. Data collection was performed by the application of a closed questionnaire, which was applied to 25 residents using the snowball technique.

Data was analyzed by categorization (Monje 2011) and descriptive statistics. Semi-structured interviews were conducted with community members, who were chosen, based on the level of knowledge and participation in community actions (specialized informants) and among people who were severely affected during the flood (key informants).

Semi-structured interviews were also conducted with personnel from local government bodies involved in flood risk management (Civil Protection Directorate, Public Works Department). In order to know the actions that they carry out in relation to the environment and their relation with risk management, an interview was carried out with personnel of the Department of Ecology. Data from the interviews was analyzed using content analysis.

Environmental Setting

The biophysical environment is characterized by the confluence of a mountainous system to the west and flood plains to the east. The climate is warm and humid with summer rains from August to October (CENAPRED 2007). Tropical cyclones from Atlantic North Region contribute significantly to precipitation.

The VUA has historically been the prevailing economic and administrative center of the region. Demographic dynamics show a positive trend, and according to projections by 2030, population growth will generate an increase of about 14.8% in the urban area, compared to 2010 (Gobierno del Estado San Luis Potosí 2012). The economically active population is 64,621 inhabitants (50.5%), of which 69% work in the tertiary sector, 20% in the secondary sector, and 11% in the primary sector, where commercial agriculture of sugar cane stands out (INAFED 2010).

According to the urban marginalization index (CONAPO 2010), 42.5% of the population are in the lower values and 47.5% have high to medium values. The Municipal Development Plan 2015–2018 indicates that the economy has low productivity and does not favor the generation of formal jobs; the urban image is deteriorated and municipal services are deficient (Gobierno del Estado San Luis Potosí 2012).

Studies show that the most important environmental changes in the region are deforestation due to the intensification of agriculture (Santacruz 2011; Navarro-Cote 2011), the growing urbanization process (INAFED 2010), and the decreased availability of water (Santacruz 2010). Among the main problems associated with the degradation of ecosystems and the environmental services they provide are land degradation, alteration in the hydrological cycle, loss of soil productivity (Santacruz 2011), water pollution, and increased disease (López-Alvárez et al. 2015).

Floods in VUA and Magisterial Community

In the urban area of Valles, where the study area is located, river floods are recurrent, especially in the areas bordering the river and forming part of the flood-prone area. Floods begin when the Valles River exceeds its critical scale, which is 5.50 m (CONAGUA 2012). In this sense, the most significant floods in the period 1955–2013 occurred in 1976 (8.95 m) and 2008 (8.30 m).

The urbanization in VUA has caused and increase the volume and change the direction of runoff (Agenda Ambiental 2009) and as a consequence the exposure to flood has increased. In addition to the floods in the flood-prone area, flash floods are occurring in intermittent streams, located in the hill areas, as is the case where the Magisterial community is located. The Magisterial was inaugurated in February 1994. It is made up of 317 inhabitants and 107 houses (INEGI 2012). The land on which the colony was built was donated to the Union of Education Workers by the municipality. The terrain is crossed by the Lajita stream and for the construction of this neighborhood, its course was modified, which caused the narrowing and increase of the sinuosity of the channel (Fig. 2).

The first flood occurred in 2004 and lasted about thirty minutes. In the lower part of the neighborhood, the water rose about 1.20 m and to be safe, the inhabitants went up to the roofs of their houses. The second flood occurred in June 2008, its duration was about 30 min. A strong noise in the stream alerted some inhabitants who, based on the experience from 2004, realized what was happening. On this occasion, water reached about 1.70 m in height

Informants reported that the second flood was more intense and caused greater damage than the one occurred in 2004 (Fig. 3). According to the respondents (80%), the greatest damage occurred was to the walls of houses and cars. The flood affected many neighborhoods of the VUA, and the impact surpassed the capacities of the local and state government, who to face the post-disaster phase requested resources from the FONDEN (DOF 2008).

Results

The questionnaire was answered by twenty-five inhabitants corresponding to an equal number of houses (27%) that present a spatial distribution with acceptable representativeness since they cover all the streets that comprise the community. 32% of the inhabitants who participated have lived in the community for at least 16 years and 52% followed the process of acquisition of the land and construction of the community. 44% are men and 56% are women, and the average age is 49 years old. 80% own the home and 16% rent. The nuclear family model predominates. 76% have university studies and 12% high school degree. It is noteworthy that 56% of the respondents are active (36%) or retired (24%) teachers.

The results were organized based on the analysis of each of the properties of resilience (Liao 2012) at the household, community, and

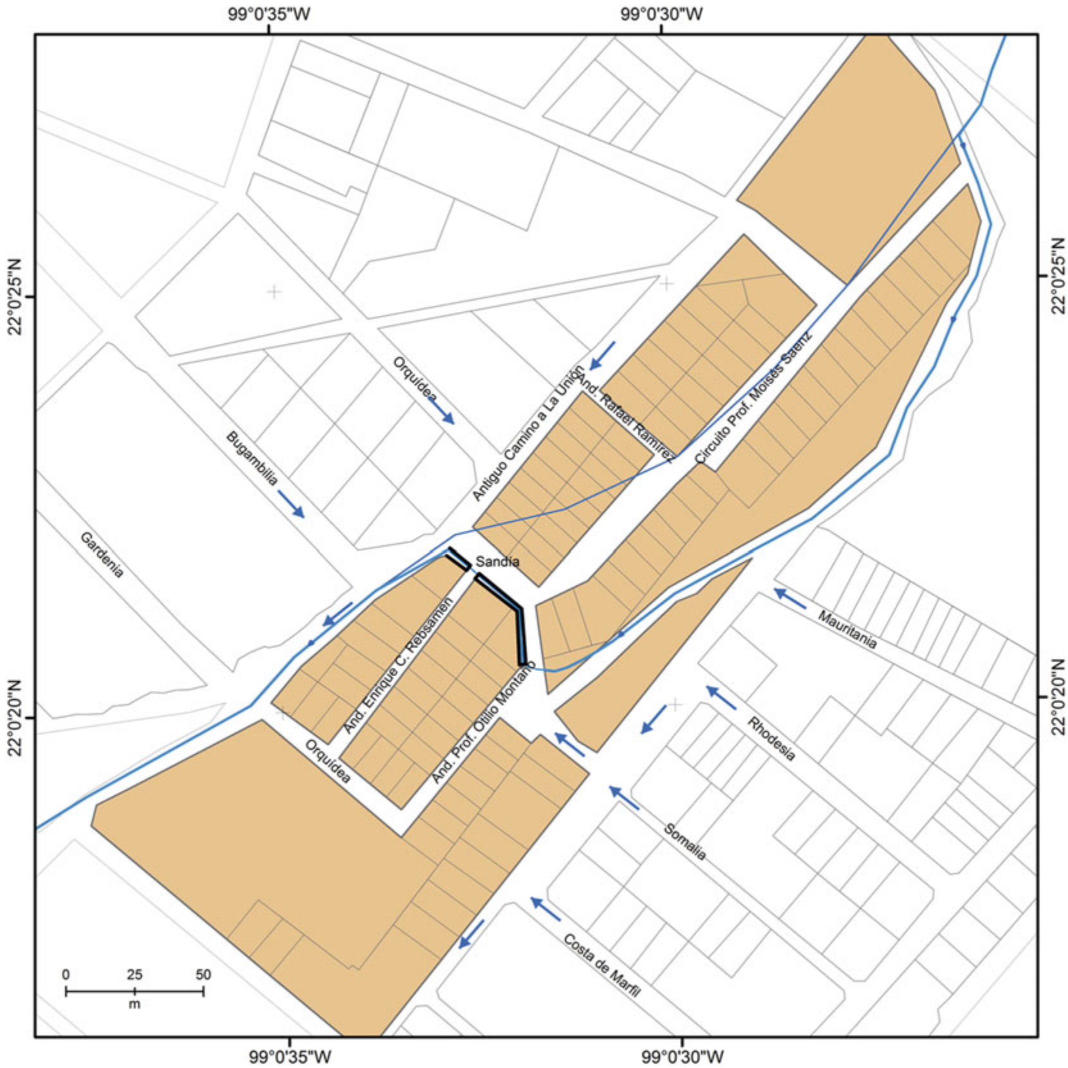

Fig. 2 Modification of the intermittent streambed La Lajita to build the Magisterial neighborhood. The thin blue line shows the original river course and the thick line the current course. The arrow shows the direction of the water runoff in the Magisterial neighborhood's streets and surroundings

municipal government levels and considering the phases of emergency, post- and pre-phases in the floods of 2004 and 2008.

Localized Response Capacity

It is defined as the ability of the system to organize itself and take measures to cope with floods regardless of external aid. The measures that the community has carried out in each of the floods are presented in Table 1. The sudden flood of 2004 took residents by surprise and after the emergency; they went to the cleaning and removal of rubbish and debris. The only measure identified in the pre-phase was the increase in the height of the retaining wall of the stream.

In the sudden flood of 2008, neighbors were again surprised, but unlike the previous flood, some people were able to alert their neighbors or to help them get safe. Subsequently, in the post-disaster phase, neighbors organized

Fig. 3 Impacts of the 2008 flash flood to the Magisterial community. (1) The immediate efforts made by the community were focused on the cleanliness of the debris. (2) and (3) Cars suffered several damages, two were dragged by the torrent of water and they were stuck in a bridge. Photos courtesy Amadeo Carbajal Orta

themselves to clean up the rubbish and debris from homes, streets, and the riverbed and to recover cars that had been washed away by the current. The pre-disaster phase begins with the organization of the community, through the establishment of a committee of neighbors, to take action in order to reduce the impacts of another flood.

The committee is still functioning and has made the following adjustments (Fig. 4): (a) modification of the channel of the stream, with expert advice extended one of the curves of the channel and built a rock wall in order to reduce the speed of water; (b) the modification of a section of the retaining wall in order to allow the passage of water since in that area during the flood of 2008 water swirled dangerously; (c) the carrying out of campaigns for cleaning of the stream riverbed in which members of the community participate voluntarily; (d) requesting, to the municipal authorities, the dredging of the stream and the provision of sand, which the community uses to fill sacks and to place containment barriers in critical sites of the stream or streets when the flow increases during the rainy season.

Both measures are carried out routinely and (e) the conditioning of a plot of land located in the upper part of the neighborhood to be used as emergency parking during the rainy season. The degree of perceived involvement of community ranged from a very high (40%) to a high (20%). The 60% of the survey respondents considers that the measures carried out have been promoted by the community and 92% have indicated that there is greater solidarity and cooperation among neighbors.

Table 1 Strategies to cope with flash floods, at household, community, and local government levels in the phases of risk management

	Household	Community	Local government
2004 flash flood			
Emergency			
Post-disaster recovery		***Cleaning*** debris	***Cleaning*** debris
Pre-disaster risk reduction	Building a second floor	Reinforcement of stream retaining wall	
2008 flash flood			
Emergency	Alert or help between neighbors		
Post-disaster recovery	Repair damages suffered indoor and outdoor	***Cleaning*** houses, streets and riverbed Recovering cars	**Cleaning** debris
Pre-disaster risk reduction	House insurance Car insurance Special savings Protect doors, etc. Protect furniture and important documents	Modification of the stream Modification of stream retaining wall Permanent cleaning campaigns Emergency parking lot	Installation of alarm system
	Place barriers of sandbags at doors	Request to ***dredge the stream***	***Dredging the riverbed***
	Moving cars to a safe place Communication between neighborhoods Attention to news about the weather or the risk communication Temporally moving to another safe place	Request sand and sacks to ***putting up barriers*** on streets or river	***Provide material to sandbag barrier***

Timely Adjustment After Every Flood

This point refers to the ability to learn after each flood and to make adjustments in aspects of behavior, physical, or institutional. In the first flood, the only adjustment promoted by the community was the modification of the retaining wall of the stream during the pre-disaster phase. In contrast, after the flood of 2008 the community has made various adjustments. The flood occurred at five o'clock in the morning, when the inhabitants were beginning their day or were still sleeping, this time some people alerted their neighbors or helped them to get to safety. From the first flood they learned the dynamics of this type of flood, the most dangerous sites due to the direction and force of the current and the places where the water would accumulate. The most outstanding adjustment is the organization of the community on its own initiative. According to the data, the causes that motivated their community organization were the damages caused by the flood of 2008, which was more intense than the previous one and the perception that the measures to face the flood by the local government are inefficient.

Redundance

This point is the diversity and replication of the measures or strategies in risk management at the levels of organization, so that if during an event, one level is exceeded, the next one can work. Redundancy was analyzed based on the number and diversity of strategies to cope with flooding at household, community, and local government levels in each of the phases of risk management

Fig. 4 Adjustments made by the Magisterial neighborhood committee. The map indicates its location. The star shows the streambed curve modified to create a backwater. (1) Retaining wall of the stream (black line in the map). (2) Modifications in the retaining wall to enhance the passage of water during flash floods. (3) Terrain conditioned as an emergency parking. (4) Signal promoting environmental care placed on the banks of the stream "if you want to feel fulfilled, happy, free, and prosperous do not throw garbage"

(Table 1). The most numerous and diversified strategies were identified at the household level, followed by measures at the community level, compared to local government strategies which are scarce and poorly diversified.

The strategies implemented by the local government during the pre-disaster phase in 2008 were as follows: Civil Protection installed eleven "alarms system" for flooding in the VUA and one of them was installed in the Magisterial community. The alarm consists of a sensor and a pair of horns that start to sound when the water of the river or stream touches the sensor, as it is the case in the neighborhoods located in the margins of the Valles River, where the sensor was installed in the houses closer to the riverbed. In the Magisterial, the sensor was installed in the channel of the stream and the horns on the second floor of a house, at a distance of about 20 m, in the lowest area of the colony. According to the interviewees, the alarm is not efficient because the time they have to get to safety once the alarm starts to sound is very brief. Furthermore, false alarms have also occurred and the sensor was stolen once. Civil Protection has not carried out a study on the effectiveness of these alarms.

To reduce the impact of floods, the local government, through the Public Works Department, performs the maintenance of streams and channels of the VUA every year to remove sediment that accumulates naturally and garbage thrown in by citizens. In this program, there is no participation of the population; however, it is considered necessary to raise awareness among the citizens as to the importance of keeping the canals and streams clean and free of debris in order to reduce floods. The realization of this activity is subjected to the existence of a budget. The local government provides sand and sacks, for the installation of barriers in the Magisterial community during the rainy season.

Discussion

Based on the information obtained, the existence of the community organization of the Magisterial community was corroborated in response to the impacts experienced during the 2008 flash flood and to the perception that local government strategies to cope with flooding are ineffective, as Mercado and Fernández (2011) point out, the failures of government intervention tend to be solved by the affected or by the intervention of nongovernmental organizations.

The aspects that have favored the organization of the community are: (a) the membership of a significant number of residents to the Magisterium, who promoted the formation of the initial committee; (b) the organizational skills associated with their profession; (c) the existence of professional and friendly relations between neighbors; (d) the existence of leadership, which has promoted community participation and made the "flood problem" visible at the local level; and (e) religion as an element of cohesion among the predominantly Catholic community, whose goal is the construction of a Church on land adjacent to the colony.

In order to cope with flash floods, the committee has promoted strategies independent of those carried out by the local government, such as: (a) modification of a section of the stream to reduce the rate of flow during a flood, (b) modification of the retaining wall of the stream, (c) permanent cleaning campaigns, (d) sandbagging during the rainy season, and (e) designation of land as emergency parking. However, the first two do not contribute to resilience because they inhibit the diversity of measures to cope with floods and when the flood occurs it is attributed exclusively to failure in infrastructure (Liao 2012) in addition to generating a sense of false security/safety (López-Marrero and Tschakert 2011).

Liao (2012) points out that the adjustments are made to be better prepared for the next flood and based on what is learned after each event, which implies an analysis of what happened and a rethinking of the strategies to be followed. In the case of the adjustments made in the Magisterial, they are based on the learning obtained after having experienced two flash floods and have been done based on their organizational and socioeconomic capacities. However, it must be considered that in decision making, factors of a different nature that give sense and meaning to the knowledge are influenced by particular social and territorial contexts (Aragón-Durand et al. 2015).

In relation to redundancy, the low contribution of the local government stands out. The possible causes to be considered are: (a) that the protocol for the management of risk in its various phases responds to the dynamics of river floods that occur in the community of the Valles River and that it is different from the dynamics of flash floods that have occurred in the Magisterial community. For Civil Protection, the Mexican government has adopted a framework of organizational practices, behaviors, and hierarchies that do not consider the experience accumulated by the communities (Macías 1999), which makes it difficult to make adjustments to respond to the changing dynamics of floods in urban areas; (b) there is a consensus among local government bodies involved in risk management that the obstruction of canals and streams due to the accumulation of sediment and garbage thrown away by citizens encourages flooding. They also point out that urban infrastructure is insufficient due to the increase in the flow volume of streams and rivers during the presence of meteorological phenomena that generate torrential rains.

However, aspects such as climate change in relation to frequency, intensity, and possible changes in the dynamics of floods (IPCC 2007),

Table 2 Factors to influence the building resilience ay Magisterial community

Promote resilience	Hinder resilience
Experience in previous disasters Community organization Community connectedness (professional and friendship relations, religion) A history of collective problems solving Community action volunteering Community leaders	Implementation of strategies focused on the control of flash floods Barriers to communicating with local government Mistrust of government Inappropriate disaster risk management Exclusion of the community in the participation of the risk reduction

or disasters and the environment (Shaw and Tran 2012), or ecosystem management for urban risk reduction (Guadagno et al. 2013; Renaud et al. 2013) are not considered within the risk management framework. In order to favor the construction of resilience, it would be pertinent to implement social learning strategies, based on existing local knowledge (López-Marredo and Tschakert 2011), with institutions that carry out research on disasters or instances that develop projects in communities, which would contribute to redefine and generate awareness (Beck et al. 2012) which through the articulation of public policies supports decision making.

Another key element in building resilience is community involvement in risk management (Thornley et al. 2015) to generate effective collaboration within a successful governance framework (Joerin and Shaw 2012). In the case of the Magisterial community, there is no community participation in risk management. At local government levels, the perception that society contributes to floods is shared and thus environmental education would help to “raise awareness” of citizens so that they do not throw garbage into rivers and streams and that they be kept clean. On the other hand, community participation in risk management decision making faces the existence of mutual mistrust between communities and local government (Valadez-Araiza 2011) and for activities of common interest between the population and government are necessary for certainty, credibility, and trust (Macías 1999).

Based on the analysis, we can establish that the Magisterial community is not a resilient community, however, with the objective of reducing the impact of floods, it has developed fundamental aspects in the construction of resilience and with external support could redefine the strategies to cope with floods. Table 2 presents the factors that we consider to have promoted or inhibited the construction of resilience in the community. In this regard, there are similarities with those presented in a study on factors promoting community resilience to earthquakes in New Zealand (Thornley et al. 2015) such as, experience in previous disasters, community organization, community connectedness, community action volunteering, and community leaders.

Conclusion

Analyzing community resilience of the Magisterial community to flash floods using the theoretical approach of Liao (2012) allowed: (a) to document the emergence and continuity of community organization, (b) to identify the strategies used to cope with floods, and (c) to identify the aspects that have favored or inhibited the construction of resilience.

The community organization came to being after experiencing the second sudden flood in 2008 and in response to the impacts experienced and the perception that local government strategies to cope with flooding are ineffective. The emergence and continuity of this organization has been favored by the existence of a significant number of teacher residents in the neighborhood, which was built to provide them with housing. Organizational skills, professional and friendly ties, leadership, and religion have served as the basis for the formation of the neighbors committee.

In order to cope with flash floods, the committee has promoted various strategies, however, both modifying a section of the stream to slow the flow rate during a flood and modifying the retaining wall of the stream do not contribute to resilience because they inhibit diversity of measures to cope with floods and when the flood occurs, this is attributed exclusively to failure in infrastructure (Liao 2012) as well as generating a sense of false security/safety (López-Marrero and Tschakert 2011).

The adjustments made in the Magisterial community are based on the learning obtained after having experienced two flash floods and in their organizational and socioeconomic capacities. However, these adjustments have not contributed significantly to the construction of resilience, which leads us to reflect on the aspects that may favor a community to make adequate decisions for the construction of resilience.

In relation to redundancy, strategies at household and community level are diverse. In contrast, the local government's contribution to redundancy is low due to inappropriate risk management, since the same protocol is used for the management of river floods and flash floods. In addition, there is a limited perception about the origin of floods and strategies for risk reduction. In this sense, interaction with external entities, which develop research on disasters, or carry out risk reduction projects at the community level, would favor the cogeneration of knowledge (López-Marredo and Tschakert 2011) for decision making.

A radical change in the paradigm of flood risk management in Mexico is required to foster community resilience, to generate social knowledge among stakeholders at all levels and with diversified and flexible risk management framework which support decision making, and that according to Aragón-Durant et al. (2015) "should be sensitive to different regional and local knowledge and contexts", so as to generate effective collaboration between community members and risk managers (López-Marrero and Tschakert 2011) in a successful governance framework (Joerin and Shaw 2012).

Based on the results, it is established that the Magisterial community, although organized on its own initiative and having made adjustments through the implementation of strategies to cope with flash floods, is not a resilient community. However, fundamental aspects for the construction of resilience have been developed.

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Quantification of Geodiversity of Sikkim (India) and Its Implications for Conservation and Disaster Risk Reduction Research

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Abstract

Geodiversity is the term which describes the variability of earth's surface materials, forms and physical processes. Conservation of geodiversity has become increasingly significant in recent decades since it has become obvious that geodiversity provides the abiotic preconditions for habitat development and maintenance and has a crucial influence on biodiversity. The Himalaya is one of the mountain systems showing highest levels of geodiversity and biodiversity. However, no research has been done on the quantification of geodiversity or on the relationships between geodiversity and biodiversity. Sikkim, located in the humid eastern Himalaya, has been selected as a study area within this global hot spot of biodiversity. The main approach of this research was to explore the geodiversity of Sikkim, using topographical and climatological information, and analyse the importance of geodiversity in the context of climate change and future conservation of natural resources. We used several quantitative approaches to produce geodiversity information which could be able to explain biodiversity patterns in the study area, since species richness models can be derived from explicit measures of geodiversity. A detailed database on species (flora) richness has been drawn from several floras and published literature. In Sikkim, the altitudinal range between 500 and 2000 m shows the highest species diversity. At higher altitudes, species diversity decreases, in particular above 5000 m. We used System for Automated Geoscientific Analysis (SAGA) GIS software for automated

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quantification of geodiversity. We produced a geodiversity index map which almost matches the high richness areas of the biological richness map by the Indian Institute of Remote Sensing (IIRS). Quantifying geodiversity indices for biodiversity hotspots such as Sikkim may contribute to biodiversity as well as geodiversity conservation, and further the understanding of geodiversity–biodiversity relationships.

Keywords
Biodiversity · Climate change · Conservation · Disaster risk reduction
Geodiversity · Sikkim · The Himalaya

Introduction

Geodiversity is now a very common aspect of physical geography and geology. In a simple way, it is defined as the heterogeneity of the geological, pedological, climatological and geomorphological properties of the earth's surface (Nieto 2001; Gray 2004, and references therein, Kozlowski 2004; Carcavilla et al. 2007; Bruschi 2007; Serrano and Flaño 2007; Panizza and Piacente 2008; Benito-Calvo et al. 2009). Importance of geodiversity has been increasing for the future monitoring of ecosystem services, particularly in a context of climate change and rising sea levels, conservation and sustainable management of environmental resources (Gordon and Barron 2012). Geodiversity has great significance for ecosystem services, economic development and vital relevance to historical and cultural heritage (Gordon and Barron 2012). Ecosystem services are typically grouped into four main categories as set out in the Millennium Ecosystem Assessment (MA) (2005) framework: provisioning, regulating and cultural services that directly affect people and supporting services needed to maintain the other services. Geodiversity has a significant role in contributing to ecosystem services, as it provides basic raw materials which effects on ecosystem processes in freshwater coastal and upland systems (Gordon and Barron 2011; Gray 2011, 2012). For example, Scotland's organic soils play a major role as a terrestrial sink of carbon which is considered in climate change mitigation and adaptation (Bardgett et al. 2011; Smith et al. 2011).

Geodiversity is an important parameter to be considered in the assessment and management of natural areas and an important natural factor underpinning biological, cultural and landscape diversity (IUCN 2008). UNESCO built the Global Geoparks Network and highlighted the cultural and economic importance of geodiversity as a means to promote geoconservation as part of a wider strategy for regional sustainable socio-economic and cultural development to save our environment (Eder and Patzak 2004). Geodiversity has been widely valued, for instance, by the Nordic Council of Ministers (Johansson 2000) and by the Australian Natural Heritage Charter (Australian Heritage Commission 2002). Quantification of geodiversity has been the focus of natural scientists in recent decades. Cendrero (1996) took first attempts to assess geological diversity and proposed that diversity of elements of geological interest and their intrinsic value, in particular, to be one of the criteria to be taken into account to classify geological heritage. He presented geological diversity on a scale from one to five according to the number of different elements present in a study area. Durán et al. (1998) contended that geodiversity assessment should consider space and time, and Gray (2004) raised awareness of the values of the geodiversity and outlined the need for a more holistic approach to nature conservation and land management.

Burnett et al. (1998) and Nichols et al. (1998) were the first authors to try to assess geodiversity employing a methodology based on the Shannon–Weaver diversity index, which was used by biologists in the assessment of biodiversity.

These early studies showed that variation in terrain and soil properties and areas of high geomorphological heterogeneity were also characterized by high values of the biodiversity index. Johansson et al. (1999), Nieto (2001) and Stanley (2001) described their idea of geodiversity including an integrative and scale-sensitive which were restricted to geological elements and processes. According to Kozlowski (2004), geodiversity includes surface waters and takes the consequences of anthropogenic processes into account as well. The main purpose of the geodiversity quantifications is the conservation of the earth resources as well as the conservation of biological richness. Benito-Calvo et al. (2009) tested landscape diversity indices to assess regional geodiversity in the Iberian Peninsula using GIS techniques. Their terrain classification generated from morphometric, geological and morphoclimatic regional classifications was applied to compute richness, diversity and evenness indices and to assess quantitatively the current regional geodiversity among the main geological regions of Iberia. Hjort et al. (2012) quantified geodiversity for a boreal landscape in Finland which was used to improve biodiversity models. Pereira et al. (2013) assessed geodiversity of Paraná State, and Silva et al. (2013) assessed geodiversity of Xingu drainage basin using geology, geomorphology, palaeontology, soils and mineral occurrence. Their main approach of geodiversity index production was to use this as a tool in land use planning, particularly in identifying priority areas for conservation, management, and use of natural resources at the state level. Pellitero et al. (2014) calculated mid- and large-scale geodiversity using lithology, structures, geomorphology, hydrology, fossils, soils and slope. Their approach was intended to promote geodiversity protection within an integrated environmental management system. But their geodiversity index should not be used as a surrogate indicator of biodiversity, as climate data were not included in calculation while it is a potential resource for biodiversity development (Parks and Mulligan 2010).

The concept of geodiversity has been put forward as a novel alternative and potentially useful means to assess and model spatial biodiversity patterns in recent years (see Parks and Mulligan 2010, and the references therein). Geodiversity includes geology, geomorphology, pedology, topography, hydrology and climate (Benito-Calvo et al. 2009; Parks and Mulligan 2010) which are meticulously linked with key abiotic drivers of biodiversity such as energy, water and nutrients (Richerson and Lum 1980; Hjort et al. 2012). Geodiversity also provides essential supporting services for biodiversity as well as the provision of minerals, nutrients, landform mosaics and geomorphological processes for habitat creation and maintenance. Fragoso-Servón et al. (2015) calculated geodiversity of the Yucatan Peninsula in south-eastern Mexico, considering geomorphology, geology, hydrology and soil properties as components of geodiversity. They used a simple additive model of thematic diversity and assured from their results that a study with detailed information could provide important insights into the spatial distribution of biological diversity. Manosso and Nóbrega (2015) identified and defined eight compartments or landscape units for a quantitative evaluation of geodiversity in a unit of Cadeado Range, Paraná State. They made an integrated analysis of the set of elements of the geoecological structure, i.e. geomorphological, geological, pedological, hydrological and socio-economic features, to understand the spatial distribution of geodiversity. Räsänen et al. (2016) explained vascular plant species richness patterns in a fragmented landscape, and according to their study, landscape and topography explained the majority of the variation, but the relative importance of topography and geodiversity was higher in explaining native species richness.

Geodiversity contributes to understand the drivers and effects of environmental change (e.g. climate change, sea-level rise and carbon dynamics in organic soils). Changes in geomorphological processes make changes in habitats, sometimes it becomes more dynamic and difficult to adapt for species. An extreme climatic event, for instance, may cause problems for freshwater and brackish water habitats when tsunami or cyclones in coastal areas destroy the surrounding ecosystem and ecosystem recovery is difficult.

Some environmental hazards, for example, coastal flooding and erosion, flash floods or landslides occur more frequently in some places, and it becomes mandatory to have strategic planning for those areas. If sufficient geodiversity information is available for those areas, it is possible to take proper action for sustainable development, risk management and geodiversity maintenance. A good example is Flood Risk Management (Scotland) Act 2009 (2009), which develops 'natural flood management and integrated catchment solutions and the restoration of the natural function of floodplains as flood buffers'. Palaeo-environmental archives and geomorphological records are able to provide long-term perspectives on trends, rates of change and future trajectories in ecosystems (Dearing et al. 2010). Geodiversity has significant values to inform about the past condition of habitats, species and ecosystems and speed of their changes. Geoconservation has been a part of statutory nature conservation in the UK for more than 60 years, and the main intention is to conserve and enhance geological, geomorphological or soil features, processes, sites and specimens, including associated promotional and awareness raising activities (Brown et al. 2012).

The quantification of geodiversity in high mountain regions is still missing, especially in the Himalayan range. The Greater Himalaya have much higher biodiversity values than the global average (Körner 2004); the eastern Himalaya have the highest plant diversity and richness within this mountain system (Xu and Wilkes 2004; Mutke and Barthlott 2005; Salick and Byg 2007). Biodiversity studies in the Himalaya include country-specific (e.g. Samant and Dhar 1997; Gairola et al. 2013) and species-specific studies (e.g. Grau et al. 2007; Srinivasan et al. 2014). However, there are still no biodiversity studies providing specific geodiversity information on the Himalayan region. Singh and Anand (2013) described the term geodiversity according to the diversity of geological features and assessed geodiversity of India and the Himalayan range qualitatively. Rawat and Sharma (2012) described geodiversity of Dabka watershed in the Lesser Himalaya for their geohydrological database modelling of a landslide susceptibility assessment. Their major geodiversity parameters were average slope, geology, geomorphology, soil types, land use, drainage density and drainage frequency, and they expressed geodiversity as least-stressed, moderately stressed, highly stressed and extremely stressed categories. They used these geodiversity categories to produce a landslide susceptibility index (LSI), but not for a geodiversity index. All these previous studies touched geodiversity issues of the Himalaya, but did not quantify geodiversity and did not specify its relationship to biodiversity. So there is a major deficit of quantification of geodiversity and biodiversity in the high mountain regions like the Himalaya. Spatial distribution of species richness has not been calculated yet for the species-rich areas in the Himalaya. The aim of this chapter is to present an automated way to quantify biodiversity from a geodiversity index, to assess species richness information for different altitudinal zones and to analyse the scope of geodiversity in the context of biodiversity conservation and climate change research.

Study Area

Sikkim is bounded by Nepal in the west and Bhutan in the south-east, Tibet in the north and the north-east, and West Bengal plains in the south. Sikkim is the least populous state in India, covering an area of 7096 km^2. Sikkim is nonetheless geographically diverse due to its location in the Himalaya; the climate ranges from subtropical to high alpine and Kangchenjunga, the world's third highest peak, is located on Sikkim's border with Nepal.

Sikkim is one of the richest treasure houses of plant diversity in the country because of its unique geographical position, high annual precipitation, a wide range of topography and the presence of perennial streams and rivers (Singh and Dash 2002). This region has a wide range of climatic conditions due to varied topography and a great deal of altitudinal variation from ca 200–8598 m (Fig. 1).

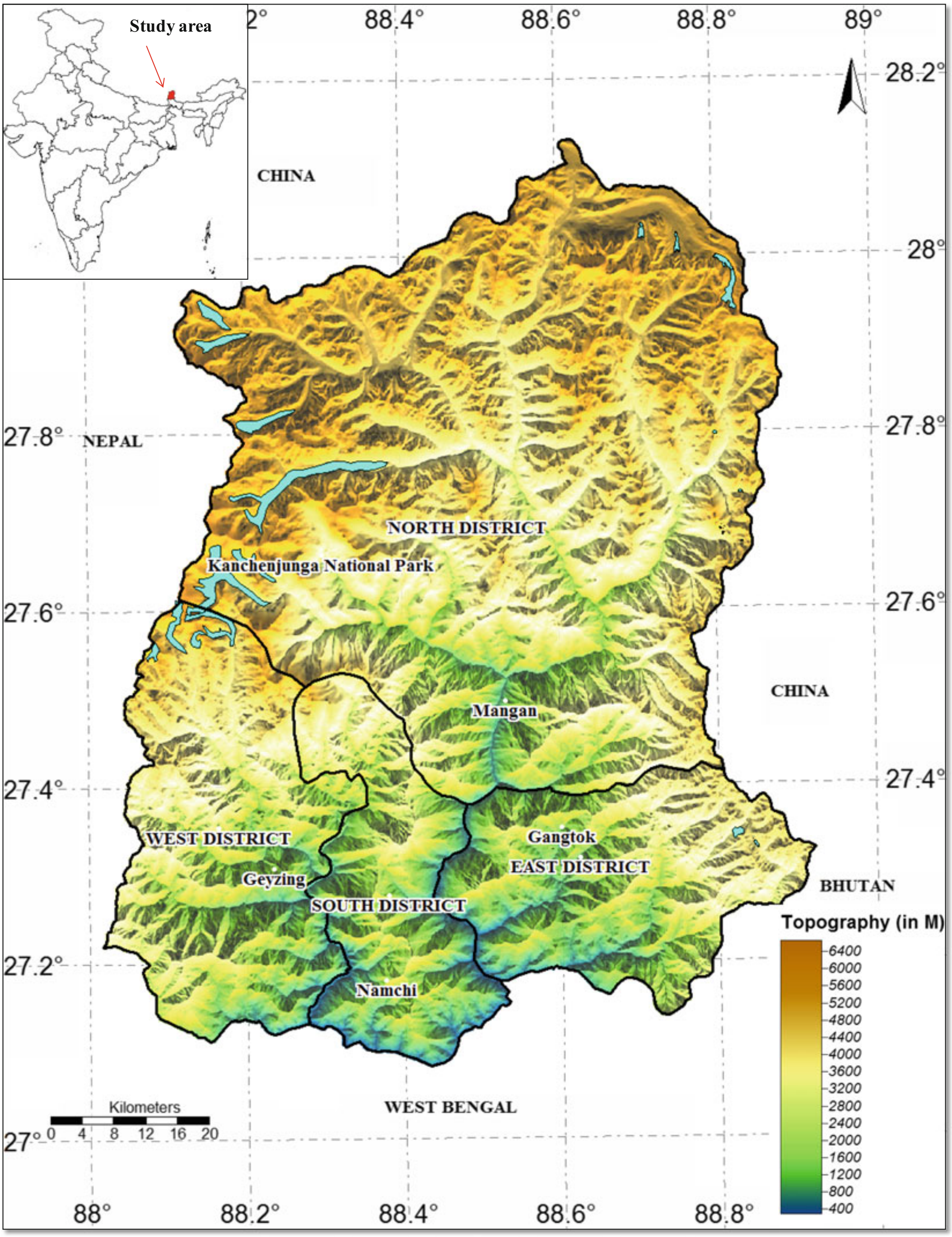

Fig. 1 The topographic map of Sikkim (map prepared by first author)

All the important forest types of eastern Himalaya like sub-Himalayan wet mixed forests, subtropical hill forests, Himalayan subtropical pine forest, wet temperate forests, mixed coniferous forests, eastern oak-hemlock forests, oak-fir forests, moist alpine scrubs and dry alpine scrubs are found in Sikkim (Champion 1936). Pure chir pine forests are the dominating feature in small pockets in dry valleys of south Sikkim, and sal forests are found up to around 900 m altitude along the valleys of Rangeet and Teesta. Singh and Dash (2002) and Forest, Environment and Wildlife Management Department of Government of Sikkim (2017) classified the vegetation cover of Sikkim according to altitudinal distribution (Fig. 2) which is summarized in Table 1.

Materials and Methods

Database of biodiversity has been produced from published floras of Bhutan and on Sikkim. A database of 5417 vascular plant species, including information on family, habitat, location according to altitude and district, and community affiliation has been prepared using published sources (Hajra and Verma 1996; Grierson and Long 1991; Singh and Dash 2002). In order to quantify geodiversity, we tried to identify the physical heterogeneity of the topography of Sikkim. This classification was elaborated using GIS techniques (SAGA 3.1.0) and has involved morphometric and morphoclimatic classification together. Classification of morphometric features was the basic task for geodiversity mapping, which was composed of morphometric variables obtained from the SRTM DEM (Shuttle Radar Topographic Mission; NASA). Temperature and rainfall data were collected from CHELSA database (Karger et al. 2016). We selected digital elevation model (DEM)-based topographical variables elevation, slope, analytical hillshading, topographic wetness index, topographic roughness index and climatological variables (temperature and precipitation) with a spatial resolution of 90 m. SRTM data had been pre-processed using fill-sinks (Wang Liu) of primary DEMs before our calibration started. Elevation data have a very high range of values (0–8000 m), and that is why this layer was normalised before calculation. Analytical hillshading calculated twice to have more emphasis on north and east facing slope values. Numbers of different physical elements were classified according to ISODATA (Interactive Self-Organizing Data Analysis Technique, SAGA GIS 3.1.0, Conrad et al. 2015) clustering methods, and each topographical variables was counted according to every coarser grid on the image. The tool 'diversity of categories' is able to count the number of categories in each cell or coarser grid. The new edition of this tool counts different classes cell by cell in a moving window using kernel method. So the changes of diversity were changed slightly from one cell to another. Another edition of this tool is search mode and search distance. Most of the previous studies counted the number of categories in each square, but here we used search mode 'circle' to show the features more natural. Search distance was another important option to count the range of diversity. Gaussian weighting function was taken 0.7 which means 70% of the distance from one cell to next 3 cells was counted for weight in diversity measurement.

Results and Discussion

We made a database on the flora of Sikkim from different published sources. Altogether there were 503 species, for which information on altitude was missing. So a total of 4914 species were used for showing their distribution. The results show that the highest species diversity can be found in the altitudinal range between 500 and 2000 m (Fig. 3). The altitude between 0 and 500 m the number of species found around 1408, from 500 to 2000 m the total number of species were 5581 and after that, the number of species started to decrease according to high altitude. At 5500–6000 m altitude, only 24 species were found in the Sikkim Himalayan range. Higher altitudes show a decreasing number of species diversity, in particular above 5000 m. Indian

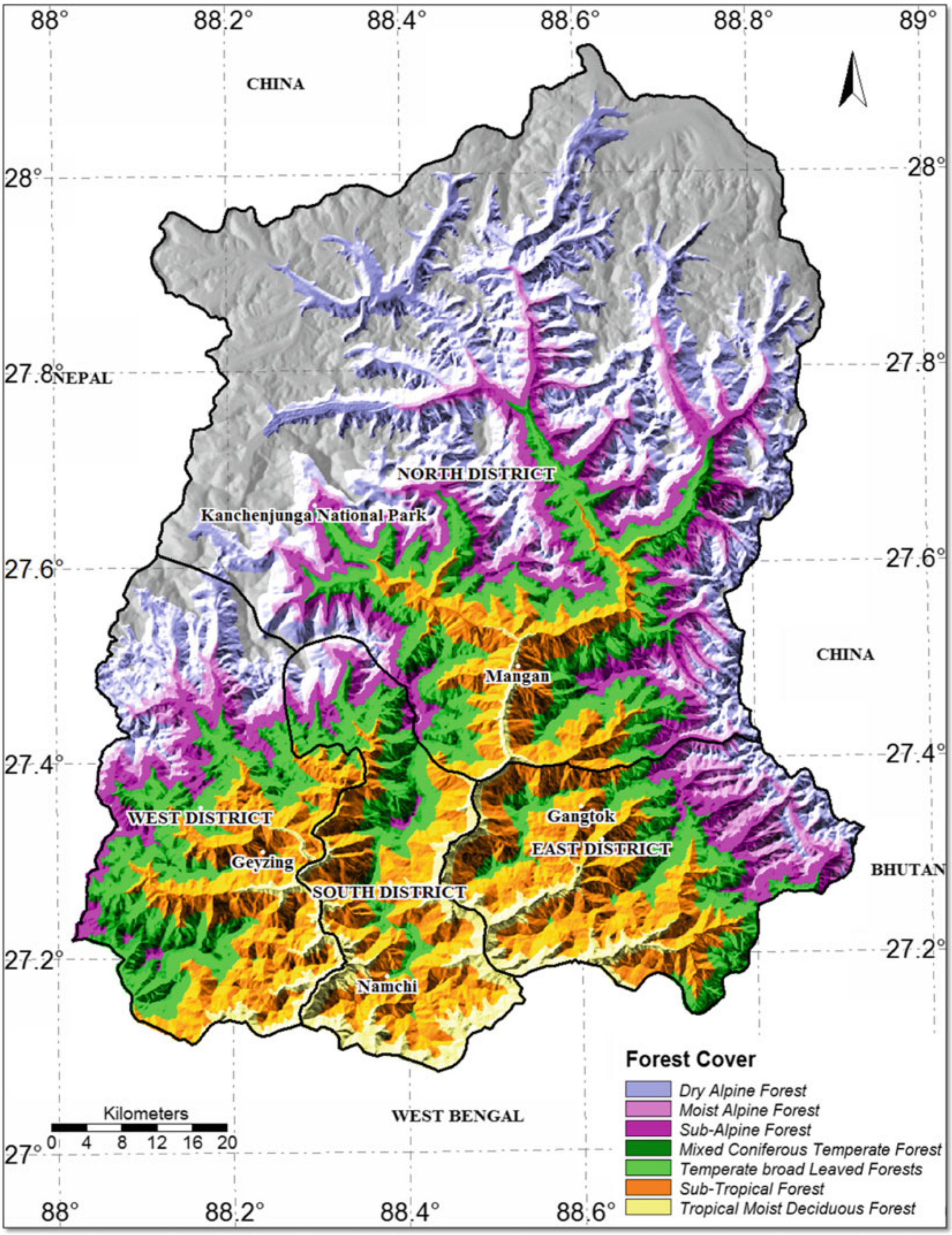

Fig. 2 Altitudinal zonation of vegetation map of Sikkim (map prepared by first author according to the information in Table 1)

Table 1 Vegetation distribution in Sikkim. *Source* Singh and Dash (2002), Forests, Environment and Wildlife Management Department, Government of Sikkim (2017)

Vegetation	Altitudinal range	Characteristics	Places
Tropical moist deciduous forest	Up to 900 m	Consist of tropical moist deciduous to semi-evergreen. Shorea robusta as a dominant species. Common species are: Saccharum spec., Oroxylum indicum, Meizotropis buteiformis	Rangpo Chhu, Sherwani, Jorethang, Rangit
Subtropical forests	Between 900 and 1500/2000 m	Mixed forest. Common species are: Adina cordifolia, Alangium chinense, Bischofia javanica, etc. Ferns and fern allies along with species of orchids constitute rich epiphytic flora of this region	Tong, Gyalzing, Sangklang Selem, Chakung Chhu, Gangtok, Gyalzing, Rongli
Temperate broadleaved forests	Between 1700 and 2700 m	Common species are: Alnus nepalensis, Betula utilis, Engelhardtia spicata, etc. Shrubby vegetation is quite dense and diverse in temperate forests	Chunthang-Lachung, Yumthang
Mixed coniferous temperate forest	Between 2700 and 3000 m	Abies densa, Acer campbellii, Betula utilis, Rhododendron, Abies densa, Taxus baccata, Tsuga dumosa, Larix griffithiana	Lachen, Zemu, Yathang, Lachung
Sub-alpine forest	Above 3000 m	This zone supports Rhododendrons, Berberis, Cotoneasters, Diapensia, Euonymus, etc.	Above Yathang
Moist alpine forest	3600–4000 m		
Birch rhododendron scrub forest		Betula utilis, Sorbus foliolosa, Rhododendron campanulatum	Thangu, Maiminchu
Deciduous alpine scrub		Berberis spec. Lonicera spec., Rosa spec.	Changu, Thangu
Dwarf rhododendron scrub		Rhododendron lepidotum	Thangu
Alpine pastures		Allium, Anemone, Delphinium	Chopta Yumasong
Dry Alpine Scrub			
Dwarf juniperus scrub	Above 3600 m	Juniperus recurva, J. wallichiana	Chopta, Changu
Dry alpine scrub	Above 4000 m	Ephedra gerardiana, Meconopsis spec., Ribes spec.	Chopta

Institute of Remote Sensing (IIRS) and Biodiversity Information System (BIS) have produced a spatial distribution of biological richness information for whole India. According to Roy et al. (2015), this vegetation type map is the most comprehensive one, developed for India so far which was prepared using 23.5 m seasonal satellite remote sensing data, field samples and information relating to the biogeography, climate and soil. Figure 4 shows the biological richness map for Sikkim produced on BIS data.

Other assessments of geodiversity used geomorphological, geological and soil features (Serrano and Ruiz-Flaño 2007b), or used geology, geomorphology and hydrology but omitted soils and topography in their assessment (Hjort

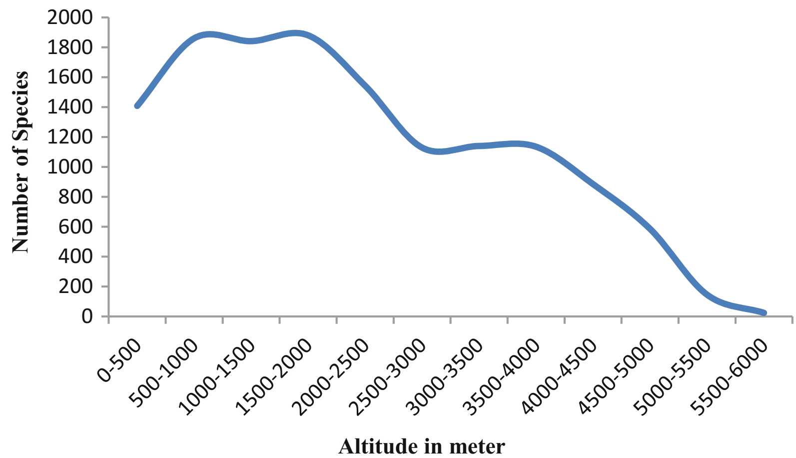

Fig. 3 Species richness according to different altitude in Sikkim

and Luoto 2010), or compiled climate and topography-based variables with geological, geomorphological and hydrological features (Parks and Mulligan 2010; Hjort et al. 2012) but all of them followed the same formula (Serrano and Ruiz-Flaño 2007b) to obtain geodiversity of their study areas. We did not include geological and soils information in our study, as the digital form of that information is not available from the free data sources and cost-effective. Benito-Calvo et al. (2009) calculated several classification maps (e.g. morphometric map, 10 classes; morphoclimatic map, 5 classes; geological map, 15 classes) to finalize their geodiversity indices, but in our method, we used all data of SRTM and CHELSA together to produce one classification map using ISODATA clustering tool, which was used to calculate diversity of categories per 90 m area. Determination of subsurface properties of soils is also difficult (Hjort and Luoto 2010) and has rarely been used as a factor for geodiversity assessment (cf. Pellitero et al. 2014 for the information of methodologies and formulae used for geodiversity calculation to date). As most of the studies follow more complex classifications and require greater computation capacity, it is comparatively easier to produce a geodiversity index using our automated method.

Geodiversity of Sikkim has been quantified and turned to normalized values from 0 to 10 and later classified as five classes with same interval, like very high (8–10), high (6–8), moderate (4–6), low (2–4) and very low (0–2) categories (Figs. 5 and 6). In case of Sikkim, geodiversity is the lowest in Kanchenjunga National Park areas. Kanchenjunga National Park area is mainly covered by several glaciers, snow fields and rocky wastes. Zemu glacier, Nepal gap glacier, Tent Peak glacier, Hidden glacier are the nearest to Kanchenjunga peak and also a place for tourist interest. There are also some other glaciers scatterd in the Kanchenjunga National park, for instance, Chungsang glacier, Lhonak North and Lhonak South glaciers in the northern part and Talung glacier, Zumthul Phuk glacier in the southern part. Geodiversity of these glaciers was found to be very low to moderate, corresponding to the low biological richness index (Figs. 4, 5 and 6). The forest of western and northern part of Mangan city (in north district) shows higher biological richness as well as higher geodiversity index. Near the eastern border of Sikkim, the area from east district to the north district has very high biological diversity as well as high geodiversity index in the produced map (cf. Figs. 4, 5 and 6a, b).

If we compare these areas with the altitudinal gradient and Fig. 2, we can see that the elevational range from 1700 to 3000 m (temperate broadleaf forest to sub-alpine forest areas) has high geodiversity as well as high biological richness. This high biological richness area consists of forest cover, alpine scrub, grass and scrub, glacial moraines and screes. In the middle

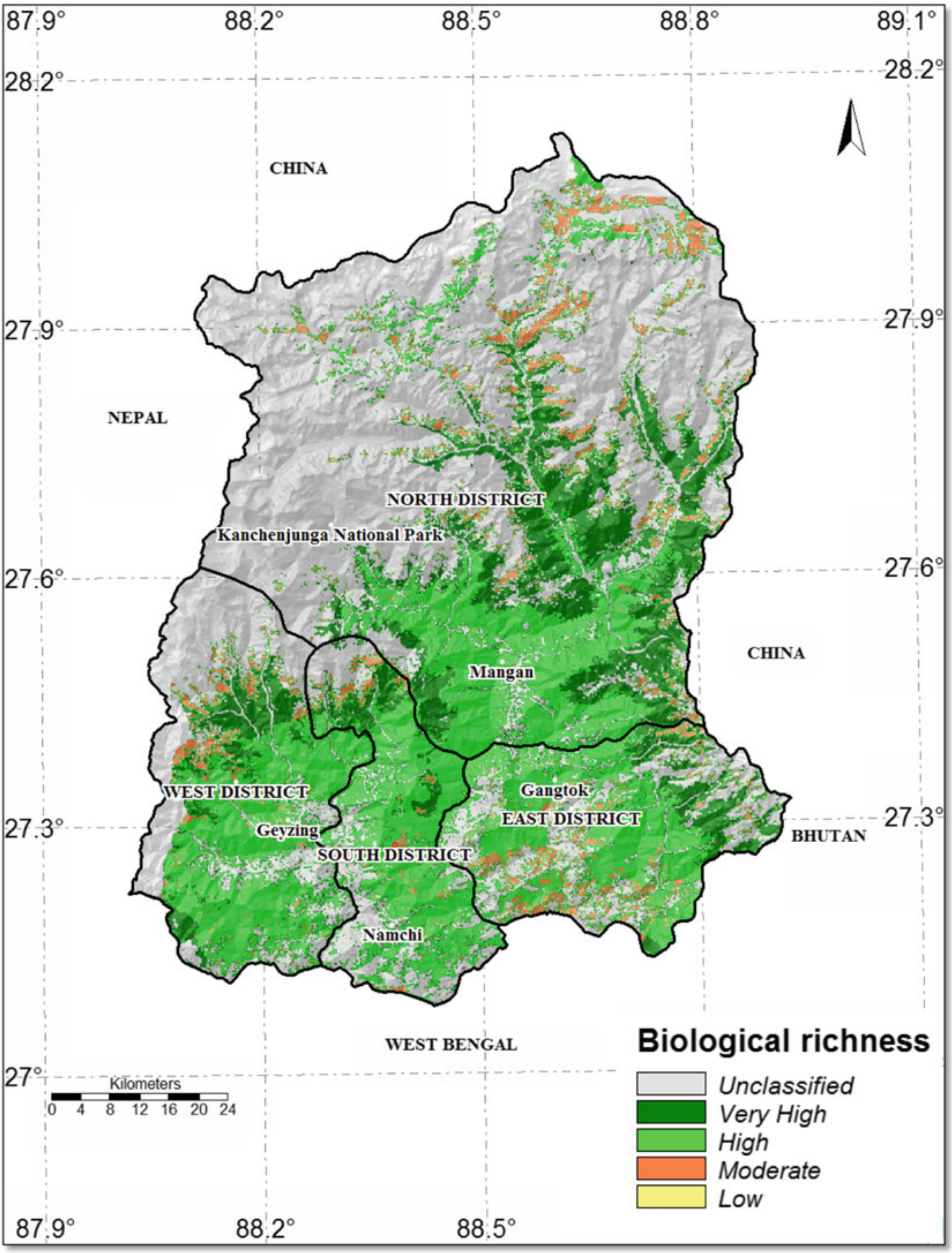

Fig. 4 Biological richness in Sikkim (map prepared by first author using data from BIS in India)

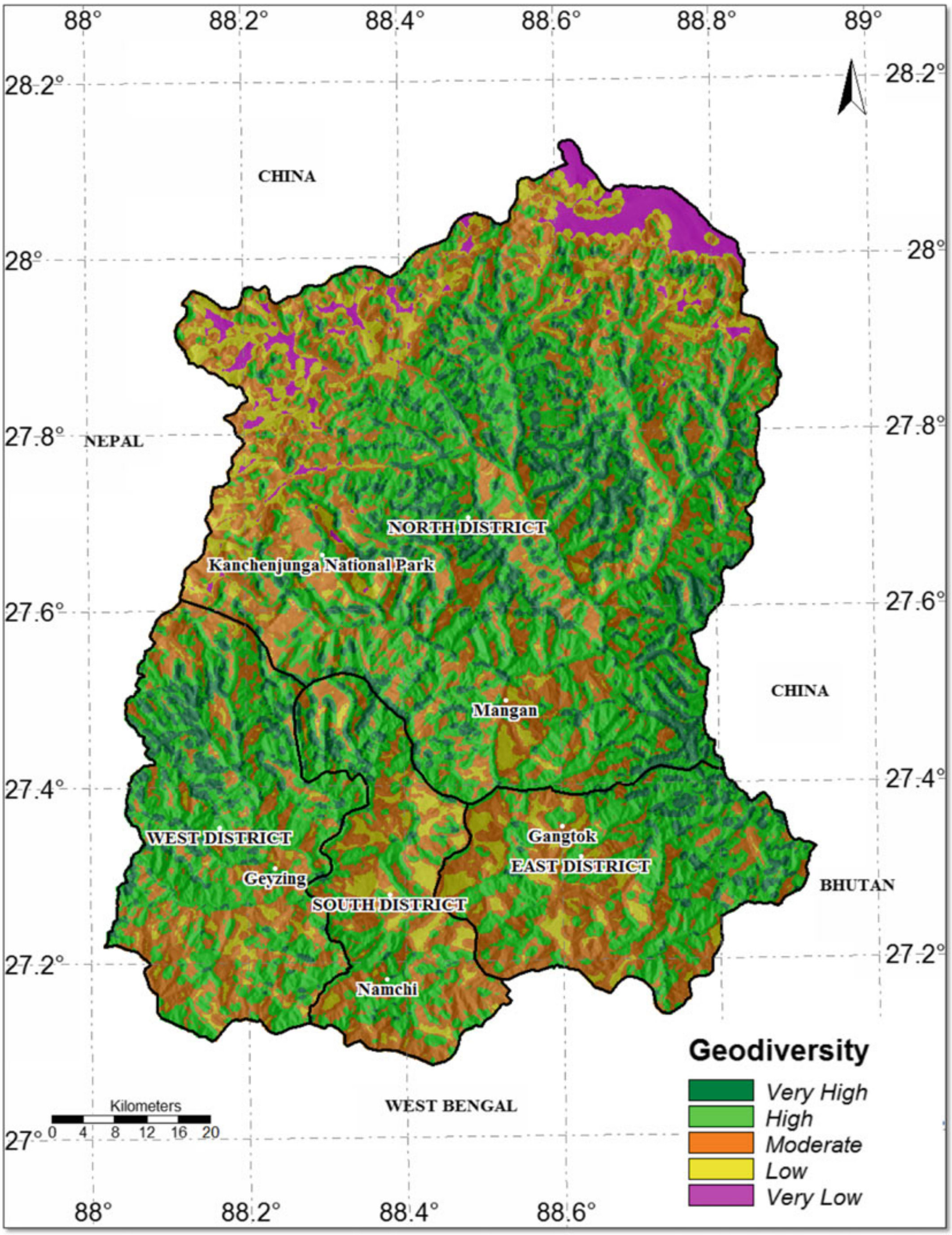

Fig. 5 Geodiversity of Sikkim (map prepared by first author)

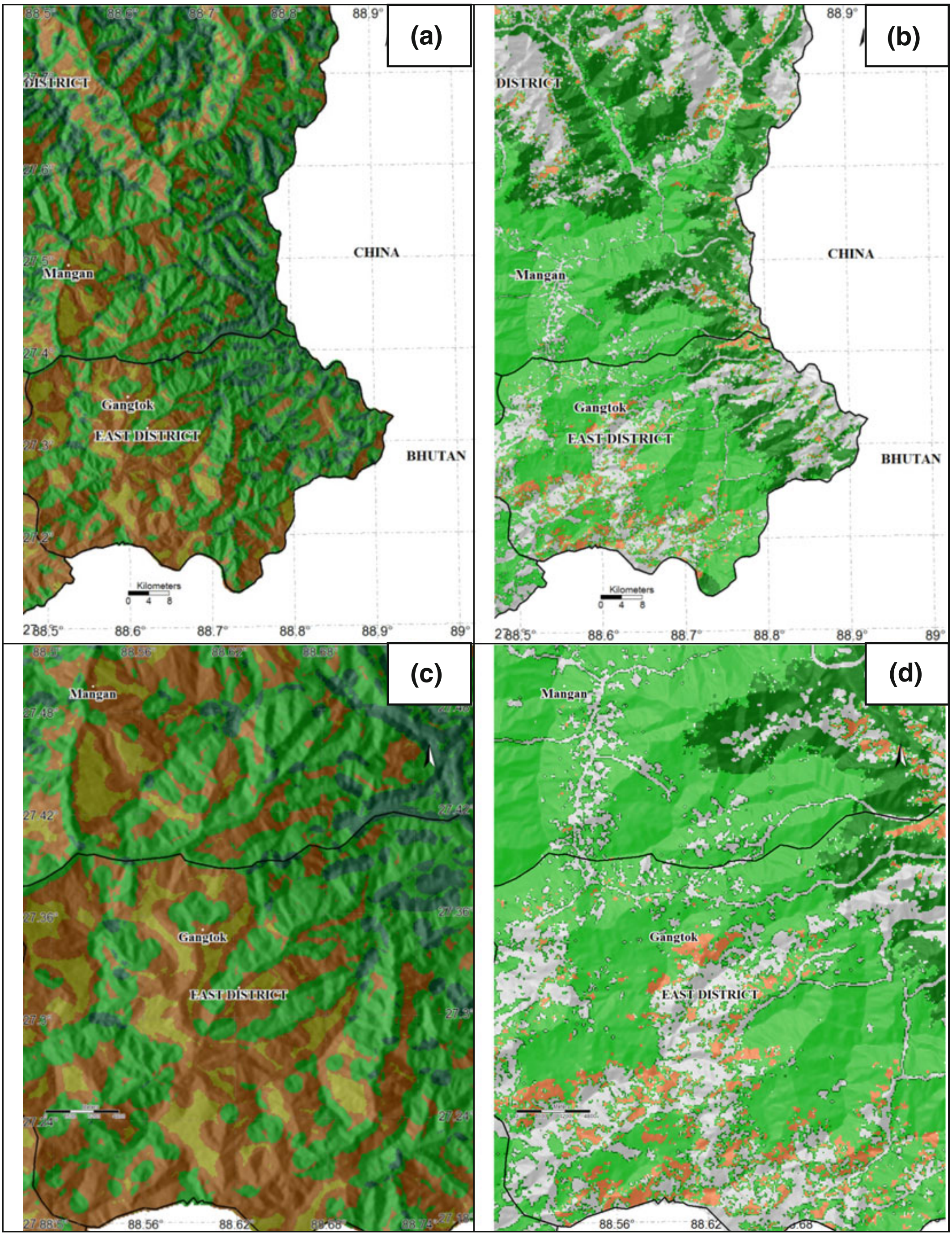

Fig. 6 Comparing of geodiversity in the eastern part of Sikkim (**a**) and biological richness, (**b**) and moderate to high geodiversity in Gangtok city, (**c**) and biological richness, (**d**) (maps prepared by first author)

of the east district, the city of Gangtok, which is the main urban settlement surrounded by agricultural fields, shows low to moderate geodiversity (Figs. 5 and 6c, d). In west district of Sikkim, the northern areas have high to very high biological diversity and geodiversity index is also shown high to very high in the map.

In the north district of Sikkim, the higher biological diversity has the shape of tree branches which almost matches with higher geodiversity areas in the same area. In the Kanchenjunga National Park, the geodiversity near the boundary of Sikkim is around 2–3, thus representing a low geodiversity index. At the same time, the biological diversity is low. The less diversified areas range from low to moderate in the southern part of the south district. Parts of the east district in Sikkim show similarly low values for both geodiversity index and biological richness. The main advantage of our method is the ability to surrogate the biodiversity information of remote unclassified areas which was difficult to produce by Biodiversity Information System (BIS) in India. As most of the studies followed more complex classification and required greater computation capacity, in comparison to them, our automated method is easier to produce geodiversity index.

The geodiversity calculation for Sikkim was satisfactory because its distribution almost matches the spatial distribution of biological richness by IIRS. The geographical organization of most geodiverse areas is strongly related to its more diverse geomorphological areas. Sikkim should be taken into account for the management of natural resources. As Sikkim is one of the great tourist spots in India, geotourism should also be focused on high geodiversity areas. Hjort et al. (2012) and references therein suggested conservation of high geodiversity areas as means to long-term biodiversity preservation, because a diverse geomorphological landscape consisting of various different abiotic habitats provides a setting for a wider number of niches available for species to occupy (Pellitero et al. 2014). Telwala et al. (2013) made a study about climate-induced elevational range shifts in the two alpine valleys of Sikkim where they found that the ongoing warming in the alpine Sikkim Himalaya has transformed the plant assemblages. According to their results, warming-driven geographical range shifts resulted in increased species richness in the upper alpine zone, compared to the ninetieth century, which can cause species extinctions, particularly at mountain tops. So conservation of species requires proper monitoring through species richness data in these mountain systems.

Implications of Geodiversity for Conservation and Disaster Risk Reduction

Sikkim is situated in a high-risk area with regard to earthquakes and landslides and is considered one of the most disaster-prone regions of India according to the multihazard map of UNDP (SSDMA 2016). In the case of Sikkim, geoconservation is threatened by natural hazards. The geodiversity index map can be used as a tool for disaster risk reduction actions and high geodiversity areas could be taken high priority areas in terms of reducing disaster risk. Deforestation can create a constant risk of landslides or other disasters in hilly regions and this should be banned for high biodiversity areas in Sikkim. Thus, strategies for sustainable conservation of geodiversity and biodiversity might significantly contribute to reducing disaster risk in Sikkim. The following steps could be undertaken to conserve biologically rich and geodiverse areas and reduce the risk of disaster in Sikkim:

- Combine the geodiversity map with the disaster-prone areas of Sikkim and take proper management action to reduce the risk of disaster for biologically rich areas.
- Increase knowledge on the areas of high-risk areas and high geodiversity areas.
- Identify scientifically driven explanations on the main causes of vulnerability caused by natural or manmade disasters in Sikkim.

- Raise awareness within local communities about conservation of geodiversity as well as biodiversity and preparedness in order to cope with potential disasters they are already exposed to.

Conclusion

In order to conserve geodiversity as well as biodiversity, the knowledge of the spatial distribution of geodiversity is a very helpful tool since it can be used as a surrogate for biodiversity to a great extent. Establishing meaningful indices for geodiversity offers novel chances for land management, more sustainable use of natural resources and identifying priority areas for nature conservation while considering both biotic and abiotic structures (Pellitero et al. 2014). Geodiversity indices are especially important for geoconservation which is highly significant for geotourism, as it focuses on high geodiversity areas, which tend to be the most spectacular (Pellitero et al. 2014). In addition, a geodiversity map is the primary requirement for mitigation of risk-prone areas and disaster management systems.

The automated technique presented here is very suitable for worldwide GIS users because all the digital information used in this method is cost-free. Scale is another important factor for this kind of mapping. Further, studies are needed to verify the biodiversity–geodiversity relationship at different scales and environments.

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Peak Discharge Analyses for Flood Management in Lower Gandak Basin

Ramashray Prasad and Jitendra Rishideo

Abstract

Flood is flow of large volume of water which is not possible to be accommodated in the preexisting channels created by the river in a fluvial system. It happens and exists for a short span of time. It occurs so because of heavy rain or snow melt water available for flow. Final, it results into spillover/overtops of water from its banks and further lead to occupy a large area in the plain. Since the Gandak Plain is heavily populated and widespread human activities are observed in the plain, spreading of water over the large area is affected adversely. It is believed that the flooding is good for replenishment of soil fertility but the transport of sand particles from the Himalayan Gandak River is the negation of this concept. It is more harmful than good. Ultimately, flood in the Bihar Gandak Plain is a curse for the land and people. It is disastrous and creates numerous types of hardship to the people. Not only that it is, sometimes, the reason for complete collapse of economy, destruction of houses and infrastructures, loss of life and property including human and cattle, and making the life miserable for all the biotic life of the area. In short, it causes widespread disaster. The flood is not only a natural one, but it is aggravated due to the interaction of human beings with its surroundings in the catchment area of any particular river basin. Therefore, this paper highlights different methods by which the flood discharge is estimated based on empirical data. Estimation of the flood discharge is helpful in designing different engineering structures to be taken up in the basin. The dealt methods here are Gumbel's extreme value distribution method, log-normal method, Ven Te Chow's method, Pearson type III method, and Foster type III method.

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Flood disaster · Flood frequency · Flood recurrence · Flood estimation
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Introduction

Flood is very common in the plain, but it is an intricate phenomenon. It is very difficult to define flood which may be acceptable to everyone. Different people consider it differently. According to hydrologists, when precipitation is greater than the drainage capacity, it is flooded. For engineers, it is the runoff which is not controlled in spite of greater efforts. For farmers, it is the water which is greater than the need of the crops. When there is interference in the communication, damage to residences, disruptions in the normal day-to-day life of people due to water, it is called a flood by general people inhabiting the area concerned. Geographers consider all the above-mentioned events to be a condition of a flood.

Flooding is a natural process in the fluvial system in which the available water for flow is greater than the carrying capacity of the channel. Most of the time, the water to discharge is supplied by the heavy down pouring rain in a shorter span or quick snow melt or combination of both. These phenomena are associated with supplying greater amount of water which has finally to be carried away by the channel. The channel has its own capacity to accommodate the water and discharge the same to downstream. Once the supply is greater and the capacity is lesser, flooding is bound to happen. Therefore, a flood is a condition in which excessively high discharge of water is spread over a comparatively flat area leading to temporary submergence. Flood is defined as 'a relatively high flow which overtakes the natural channel provided for runoff' by Ven Te Chow (1956). Ward (1978) defined the same as 'a body of water which rises to overflow land which is not normally submerged.' In other words, it may be stated that the level at which the river channel overflows its banks and submerges the surrounding area is referred as flood situation (Mutreja 1986; Subramanya 1988). Rostvedt (1968) defines flood as 'any high stream flow which overtops natural or artificial banks of a stream.'

Flood is an event which may be caused at different scales and by different mechanisms. Flooding may be caused by excess availability of water due to different reasons discharged through the river. It is generally called a riverine flooding. The little additional available water may be a reason to create flood in an urban area where the drainage is clogged. The draining is not possible in a quicker way, and hence, it is termed as urban flood or flood caused by drainage congestion. In the mountainous region, sometimes floods are also caused due to mudflow in huge quantity along the slope. Subsidence of land near larger water body is also a reason of flooding. When seismic waves are propagating during earthquake through unconsolidated and saturated soils, they allow the soil particles move freely. It leads to fissure eruption on the surface. Through these fissures, subsurface water is propelled and reaches to the surface. This type of flooding was caused during January 15, 1934, Nepal–Bihar earthquake (GSI 1939). Soil liquefaction study was conducted by Nepal–Bihar earthquake on August 21, 1988, by Mukerjee and Lavania (1998). Whether it is mudflow or subsidence or liquefaction, all are clubbed together to call the flood caused by ground surface failure. Coastal areas are also subjected to flooding by ocean waves particularly during cyclonic storm or at the time of tsunami and are referred as coastal flood.

Since the present study is concerned with the Gandak River, here the emphasis is on riverine flood.

With respect to Gandak River, the flood is caused mainly by torrential rain in the upper catchment during monsoon season associated with quick snow melt in the higher altitude due to high temperature during June to September. Floods are recurrent features in the adjoining areas of high discharge carrying rivers all over the world. Where the flood inundate, a large-scale after effects are observed like soil erosion, land degradation, crop damage, shelter collapse, loss of life and property, spread of waterborne various diseases, hunger, epidemics, and other related hardships. These sort of problems are directly associated with the Gandak River basin. These are some of the examples of disaster caused by flood. Flood is a recurrent feature in the Gandak River basin. It happens several times in a year during monsoon months. There may be several peak flows of the river, and every time, it causes the flood to happen.

Literature Review

The shape and size of the basin has a direct bearing on the nature of the flood in the said basin. The basin and its scale in flood peak distribution are studied very suitably by using a log-normal model by Smith (1992). Gupta et al. (1994) used the multi-scaling theory of floods for regional quantile analysis. A very good reporting on flood situation and flood management concerning India and Bangladesh has made by Prasad and Mukherjee (2014). A detail guideline for analyzing extreme floods has been prepared by Ruttan (2004). Subramanya (1988) discussed about the flood estimation using different methods and also deliberated on its control. Different aspects of flood and flooding in the Ganga basin and its tributaries have been studies by Dhar and Nandargi (2002). Rao and Hamed (2000) have studied in detail about the analysis of various methods for estimating the peak discharges. Prasad (2009) has tried to estimate the peak flood for Kosi River at Barahkshetra using 46 years of peak data. Mutreja (1986) has deliberated much in detail about many methods of peak discharge analysis and estimated the recurrence of probable peak for numerous periods which are yet to come in future. The main purpose of this study is to (a) identify the flood genesis, (b) estimate the peak discharge based on empirical data, and (c) throw light on the grim situation due to flood and the measures to be adopted to minimize the loss in the Gandak Plain of Bihar.

The Study Area

The Gandak River is known as Kali Gandaki in Nepal, but the same river is termed as Narayani in the southern Nepal areas of foothills. It is an antecedent river which means it is older than the Himalayas. It has got its origin from the Tibetan plateau and cuts the Himalayas during its rising periods. It has created the world's deepest gorge 'If one measures the depth of a canyon by the difference between the riverbed and the heights of the highest peaks on either side, the Gorge is the world's deepest'—CWPRS (Central Water and Power Research Station 2012). The Himalayan catchment of the Gandak River encompasses 1025 glaciers and 338 lakes. The Gandak River enters India (Bihar) at Triveni. Here, the river debouches in the plain. Prior to this, the riverbed slope is very steep but further downward, the slope keeps on declining slowly. The greater slope in the upper catchment, crushed rocks due to the Himalayan orogeny, and extensive weathering associated with heavy torrential rain during monsoon months produce enormous sediment. It is carried by the river, but when it reaches at the foothills, the huge deposition is deposited because of the lowered carrying capacity of the river. It has led to the formation of the Gandak mega fan (Geddes 1960; Wells and Dorr 1987; Prakash and Kumar 1991). This mega fan consists of eroded sediments from the upstream and brought and deposited by the Gandak waters. The deposited materials in the plain are loose and unconsolidated, and They get eroded easily further. In the high surge of water in the river, sometimes they lead to shift the channel by carving out another in the nearby. It happens when the existing channels are chocked by sediment and the water is not channelized quickly. Hence, the channel shift is the evident in both major rivers of north Bihar, the Gandak and the Kosi.

The area under direct study lays downstream to Triveni, particularly after Valmikinagar barrage near Nepal–Bihar border. It is the lower Gandak basin which falls partly in Uttar Pradesh and major portion in north Bihar plain. This area lays between 25° 21′ 23″N to 27° 26′ 54″N latitudes and 83° 49′ 00″E to 85° 15′ 52″E longitudes (Fig. 1). It is a total area of 7370 km^2 out of which 968 km^2 lays in Uttar Pradesh and 6402 km^2 in Bihar. The water rushing from the upper catchment is the main cause for water accumulation and causing flood in the downstream. Therefore, the first para mentioned under the study area is also having great importance in terms of understanding the flood problems. The total length of the embankments along both sides of the Gandak River is 512 km (Baghel 2014). They start from the foothills to downstream through Valmikinagar barrage.

The Gandak River Basin and Its Characteristics

The Gandak basin is a sub-basin, occupying the eastern central place, in the Ganga River basin. The Gandak River gets its origin from Tibetan highlands of Trans-Himalaya from Nhubine Himalaya Glacier at a height of about 6268 m above sea level and confluences with Ganges near Hajipur opposite Patna where the elevation is only 44 m. Along its journey, it covers a distance of about 630 km with a total basin area of around 45,035 km^2 out of which about 9540 km^2 is in Indian Territory. Around 10,000 km^2 area (partly in Nepal) lays in the plain and rest is the mountainous catchment in Tibet and Nepal. The ratio of plain and mountain area is 1:4.5 (Fig. 2), a very big one. Rain and melt water from such a large area with very steep slope generates runoff which quickly reaches to the plain. The slope in the plain becomes very low and huge amount of water along with concentrated sediment have to be drained. Due to this condition, the carrying capacity of the lower channel is reduced drastically. Hence, the spread of water over a large area is the result leading to flooding. The mean annual water flow of the Gandak River at its confluence with the Ganges is about 52,200 million cubic meters (Dhar and Nandargi 2002). The maximum discharge recorded at Triveni (near Bihar–Nepal border) is 12,700 cubic meter per second (cumec) in 1986, and at Lalganj (in Bihar, Vaishali district), it is 15,750 cumec (Rishideo 2011) in 2001.

The Gandak River and its many tributaries are getting their origins at high altitudes in the Himalayas from glaciers. There are numerous springs from where the water is channelized to the streams, and hence, the Gandak is a perennial river. Huge amount of sediment is produced from the upper Himalayan catchment and deposited in the plain areas. Since the deposited sediment is loose and unconsolidated, the bed is very much unstable. Meandering is routine affair of the river in the plain. Dam construction is possible only in the mountainous region in Nepal and hence, the reservoir may be there. There is no such scope in the plain to do for flood control. It all depends upon the understanding between two nations as it is a trans-boundary river. It is a well-known fact that the answer of the flood is not laying the plain, but it is has its genesis in the upper catchment. It is possible through the overall land and all human activity management in the upper reach of the river. Most of the time flood becomes uncontrollable not because of the excess of water, but it is the excess of sediment charge from the river water. If the sediment coming from the running water is regulated/controlled/trapped in the initial stage, the flood may easily be regulated as well. Therefore, the international territorial extent of the upper catchment is one of the prime reasons of the failure of the land and human activity management. In fact, the integrated approach is the need of the hour not only for the benefit for India but for the benefit of Nepal as well. Both of the country would harvest the benefit by sharing and caring the need of each other.

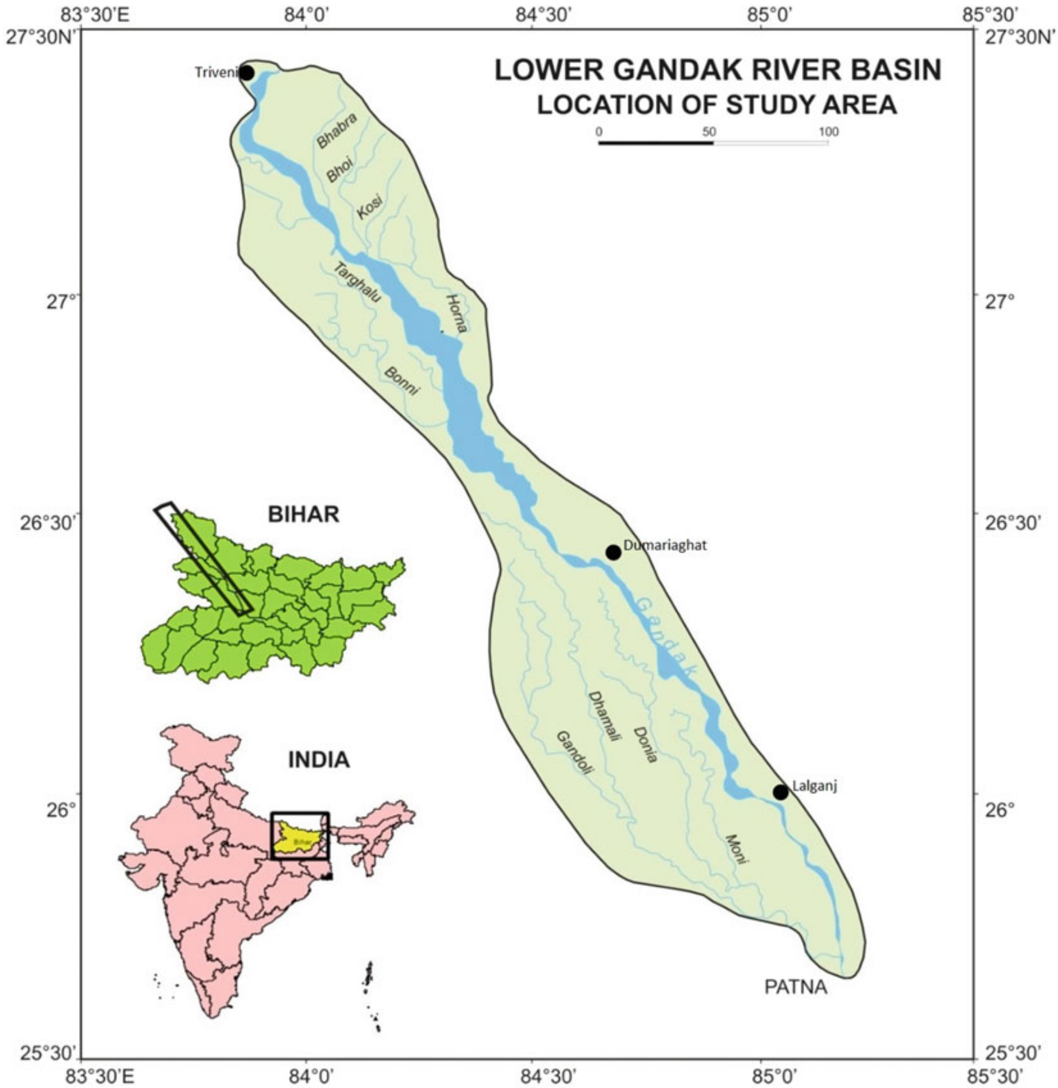

Fig. 1 Lower Gandak River basin

Rainfall Distribution

The pattern of precipitation distribution in the upper Gandak River basin of the Himalayan catchment areas is quite distinctive. The entire upper catchment area of the Gandak River basin can very well be divided into four ecological zones on the basis of its elevation. They are Trans-Himalaya, high mountains, hills, and Tarai. The lowest annual average precipitation is observed in the northern zone of the Trans-Himalaya where it is just 55 cm and relatively more in the high Himalayan areas with a precipitation of around 150 cm annually. But the lower altitudinal zone of hills receives the highest annual average rainfall which is about 347 cm. Tarai region experiences a little less rainfall where it just 195 cm. The mean annual precipitation in the upper Himalayan catchment area of the Gandak basin upstream to Triveni is 186 cm (Panthi et al. 2015). The topography and altitude have very important role in the distribution of precipitation in the basin. There is significant

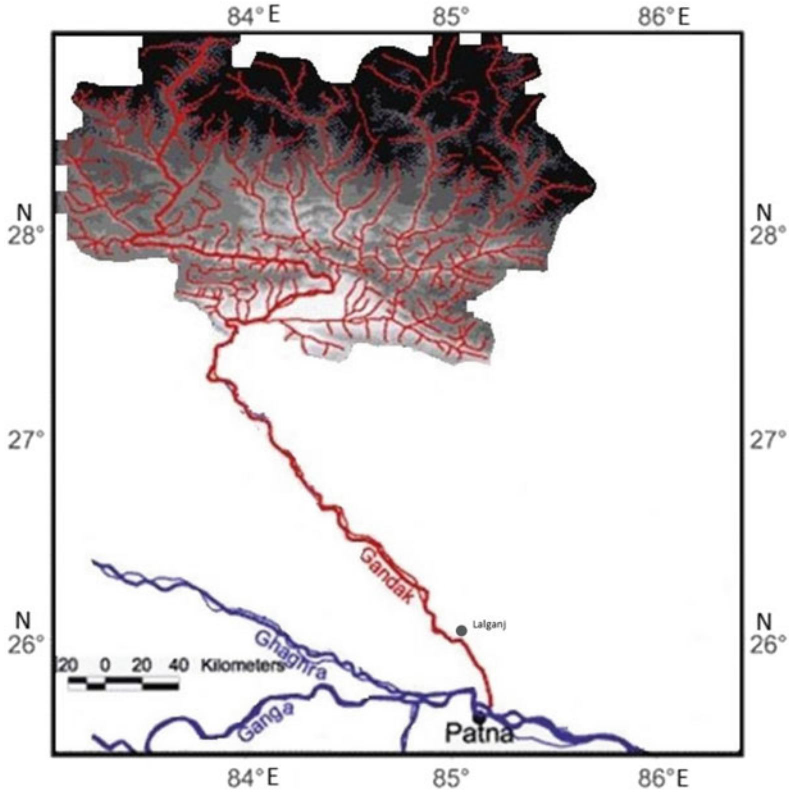

Fig. 2 Gandak River catchment in the mountain and plain

variation in the distribution of precipitation over the seasons as well as subregions mentioned above. Periodic variation of precipitation in the basin is also very distinctive. About 78% of the total annual precipitation in the Gandak River basin is received within four monsoon months (June–September). Remaining 22% rainfall is spread over a period of eight non-monsoon months (October–May).

The mean annual rainfall for the entire river basin in the plain is 120 cm (Ranade et al. 2008). The flood and its havoc are created by the runoff coming from the mountainous catchment where the slope is very steep. Runoff is very swift, and it reaches the lower basin quickly. As stated above, the real solution of the flood in the Gandak Plain is laying in the upper catchment. Hence, the action needs to be taken there to tackle the flood problem.

Data Source and Methodology

The present study is based on secondary data. The data is related to the peak discharge recorded at Lalganj discharge site. The peak discharge is defined as a single maximum recorded discharge within a calendar year. This data has been collected from the Gandak Division of the Ganga Flood Control Commission (GFCC) at Patna Secretariat. This data is utilized to estimate the probable discharge in the years yet to come. It is known as discharges for recurrence years. It is analyzed on the principle of extreme value distribution techniques. The techniques used here are five in numbers. They are given below and the methods adopted for estimation of floods by these methods are discussed simultaneously while discussing those techniques.

Flood Frequency Analysis

Flood frequency analysis is a method of investigation in which the single maximum discharges of different years are used to estimate the probable discharge for a certain interval based on different methods. Sometimes, it happens that the highest discharge in 365/366 days of a particular year may be less in comparison to the several discharges in another year which are not included. By the assumption of the peak discharge analysis method, only one highest discharge is included in the data set and not the others which may be even larger than other year's highest. Reasonably bigger duration random data from the sample representing the universe is the prime concern for this analysis. Hence, by the use of this type of data, estimation of discharge for certain return period is helpful in determining different measures to be adopted in the area to protect from the vagary of floods. Once the likely discharge is known, some engineering structures may be created in the field to tackle that much of discharge. In this regard, there may be several measures like construction of several dams/check dams in the upper catchment, barrage, diverging water from the main river to other adjoining areas, embankments in the plain, dredging of riverbed, creating several storages. All these could be possible when precise and appropriate estimation of discharge is computed.

The estimation of discharge in the future could be estimated based on the available data by different methods. It is always fair to use long-duration data for better analysis and precise prediction. When the long-period data is available with correct figures, it delivers very accurate, suitable, and reliable results. Based on this information, a fair degree of precise and accurate extrapolation could be done. There is no set pattern about the limit of extrapolation period. Many of the hydrologists give their opinion, but K.N Mutreja (1986) says, 'some hydrologists set a limit of extrapolation of about twice the length of record, i.e., a 50-year runoff data can be used to determine the magnitude of events up to 100 year flood but not of a longer return period, while others do extrapolate runoff record of 40 to 100 years in length to estimate a 1000-year or even 10000-year flood.' The flood estimation for varying recurrence interval could be possible to have by using the mathematical equation as well as graphically by plotting the values on probability graph paper. The present analysis is based the recorded peak discharge of Gandak River at Lalganj for a period of 33 years from 1981 to 2013. There are five methods used here—they are —Gumbel's method, log-normal method, Ven Te Chow's method, Pearson type III method, and Foster type III method. They are discussed below:

Frequency Factor

The method of frequency factor is the application of statistical procedures. The techniques based on frequency factors can be formulated. It is a represented through the following formulae equation:

$$X_t = \bar{X} + K\sigma$$

where

X_t = flood magnitude of given return period T,
$\bar{X}$ = mean of recorded peak floods,
σ = standard deviation of recorded floods, and
K = frequency factor which depends upon the return period, T and the assumed frequency distribution.

Chow (1964) has expressed that the most frequency distribution functions applicable in hydrologic studies have been expressed by the above-mentioned equation. This formula is commonly known the general equation of hydrologic frequency analysis.

Gumbel's Method

This method was introduced by Gumbel (1941) and is commonly known as Gumbel's extreme value distribution method. Gumbel was the first to realize that the annual peak flood data (or annual maximum one storm rainfall and similar type of data) is nothing but the extreme values in different years' observation. It is one of the most widely used probability distribution functions for extreme value in hydrologic studies for prediction of flood peaks, maximum rainfall, maximum wind speed, etc. concerning the extreme events. From the first equatation mentioned above, the frequency factor, K is expressed as:

$$\frac{yT - \bar{y}N}{Sn}$$

where

$\bar{y}N$ = reduced mean, a function of sample size N and it is taken from the given table (Subramanya 1988: p. 215),
Sn = reduced standard deviation, a function of sample size N and it is taken from the given table (Subramanya 1988: p. 215), and
yT = reduced variate, a function of T and it can be calculated by

$$yT = -\left(1n.1n.\frac{T}{T-1}\right).$$

Example, for a return period of 50 years, yT, is:

$$\begin{aligned} yT &= -\left(1n.1n.\frac{T}{T-1}\right) \\ &= -\left(1n.1n.\frac{50}{50-1}\right) \\ &= -(1n.1n.50/49) \\ &= -(1n.1n.1.0204) \\ &= -(1n.0.020202707) \\ &= -(-3.901938658) \\ &= 3.901938658 \\ &= 3.9019\,(\text{rounded off}) \end{aligned}$$

All these equations have been used under the following steps to estimate the flood magnitude corresponding to a given return based on an annual flood event.

Procedures

(a) Assembled the peak discharge data in descending order,
(b) Computed the mean ($\overline{X}$) given variate
Mean ($\overline{X}$) = ΣX/N,
(c) Found out the standard deviation (Ϭn − 1) $= \sqrt{\sum(xt - \overline{X})^2/N}$ of the sample,
(d) Determined $\overline{yn}$ (reduced mean) and Sn (reduced standard deviation) to the given N:
Found out the yT for a given T yT = − (1 n.1n.T/T − 1) and
Found out the frequency factor, K = yT $-\overline{yn}$/Sn, and
(e) Computed the required magnitude of flood xT
X_t=$\overline{X}$ KϬn − 1.

Discussion

The estimation of peak recurrence at Lalganj on the Gandak River has been computed based on the above-mentioned procedures/steps and the results of the same are presented in Table 1 below. The peak discharge data collected from the field has been used here. It belongs to 33 years from 1981 to 2013 for the said discharge site. The first column of the table is showing different return periods and the same is converted into probability in percentage in the column second. From these two columns, it is clear that the higher period of recurrence of peak discharge has very low probability and vice versa. It is the basic principle of the return period of flood event and its probability.

The average peak discharge for entire period under study at Lalganj is 9343 cumecs. For a return period of 1000 year, the computed peak discharge is 24822.58 cumecs which is quite a large value in comparison to the mean or even the observed discharge. The maximum discharge for 33 years is only 15750 cumecs under records. With higher return periods, it increases very rapidly, but its probability decreases very drastically. It had been estimated that a flow of

Table 1 Flood frequency analysis of Gandak River at Lalganj: Gumbel's method (1981–2013)

Return period T (Years)	Probability P (in %)	$\overline{X}$ (in cumecs)	yT	$\bar{y}$N	Sn	$K = \frac{yT - \bar{y}N}{Sn}$	ϭn-1	$X = \overline{X} + K$ϭn-1
1000	0.1	9343	6.9073	0.5384	1.1211	5.6809	2724.85	24822.58
200	0.5	9343	5.2958	0.5384	1.1211	4.2435	2724.85	20905.89
100	1	9343	4.6001	0.5384	1.1211	3.6230	2724.85	19215.12
50	2	9343	3.9019	0.5384	1.1211	3.0002	2724.85	17518.09
10	10	9343	2.2504	0.5384	1.1211	1.5271	2724.85	13504.11
5	20	9343	1.4999	0.5384	1.1211	0.8576	2724.85	11879.83
2	50	9343	0.3665	0.5384	1.1211	-0.1533	2724.85	8925.28
1.2500	80	9343	−0.4759	0.5384	1.1211	−0.9047	2724.85	6877.83
1.0526	95	9343	−1.0974	0.5384	1.1211	−1.4591	2724.85	5267.18
1.0101	99	9343	−1.5272	0.5384	1.1211	−1.8425	2724.85	4322.47

4322.47, 8925.28, 11879.83, 17518.09, 19215.12, 20905.89, and 24822.58 cumecs discharges are expected to occur in 1.01, 2, 5, 50, 100, 200, and 1000 years at Lalganj. The return probabilities for those discharges are 99, 50, 20, 2, 1, 0.5, and 0.1%, respectively. However, it is important to note that all such recurrence intervals of hydrologic processes are simply averages and do not indicate when an event of a particular magnitude would occur. It is often very difficult to accurately estimate the recurrence interval of an extreme and rare event due to unpredictability of the nature and natural events.

Log-Normal Method

Log-normal method is based on the principle of log-normal probability law. This method assumes that the flood values are such that their natural logarithms are normally distributed. The computation of this method has carried out in following steps.

Procedures

(a) Computed the ($\overline{X}$) of the given variate Mean ($\overline{X}$) = ΣX/N and found out the standard deviation (ϭn − 1) by $= \sqrt{\sum(xt - \overline{X})^2/N}$ of the sample N,

(b) Computed the coefficient of variation Cv, Cv = ϭn − 1/$\overline{X}$,

(c) Found out the coefficient of skewness C_s, $C_s = 3(Cv + Cv^3)$,

(d) Determined theoretical log-probability (K) frequency factor corresponding to the computed value of C_s and selected probability (P) from the Table (Mutreja 1986: p. 708),

(e) Computed the value Kϭn − 1, and

(f) Added $\overline{X}$ to get the required magnitude of flood.

Discussion

The results of the flood frequency of the Gandak River at Lalganj site by log-normal method have been presented in Table 2. It is clear that the flood magnitude is changing with their probability. Higher discharge is associated with higher return period of occurrence and lower probability, whereas the lower discharge is related to higher probability and lower return period of occurrence. According to this method, the discharges of 13335.25, 17436.25, 11414.00, 8961.50, and 4601.50 cumecs are estimated for the return periods of 1000, 100, 5, 2, and 1.01 years, respectively. It is based on the data for 33 years at Lalganj discharge site as mentioned above.

Table 2 Flood frequency analysis of Gandak River at Lalganj: log-normal method (1981–2013)

Return Period (years)	Probability P (%)	$\overline{X}$	C_s	K (for C_s = 0.9)	K_s	$X=\overline{X}+K_s$ (in cumec)
1000	0.1	9343	2725	4.55	12401.25	13335.25
100	1	9343	2725	2.97	8093.25	17436.25
5	20	9343	2725	0.76	2071.00	11414.00
2	50	9343	2725	−0.14	−381.50	8961.50
1.2500	80	9343	2725	−0.84	−2289.00	7054.00
1.0526	95	9343	2725	−1.37	−3733.25	5609.75
1.0101	99	9343	2725	−1.74	−4741.50	4601.50

V.T. Chow's Method

V.T. Chow's method is the graphical fitting process. The observed peak discharges are plotted on the probability graph paper. After the plotting of values, a line is drawn which suits the best. It could be drawn by simply observing the plotted values. But to avoid the visual/subjective error of inspection, it is generally drawn mathematically. This method is known as V.T. Chow's method. In fact, this method is a modification of Gumbel's method. The procedures of computation by this method are as follows:

Procedures

(a) Arranged the peak discharge figures in descending order,
(b) Assigned the rank values for those figures as first for the highest flood and the last for the lowest one,
(c) Found out the return period, T = N + 1 divided by the weight given in step 'b',
(d) Got the Z which is equal to log.log [T/(T − 1)],
(e) Found out XZ by multiplying respective peak discharge with the Z in step 'd',
(f) Got Z^2, i.e., step d×d, and
(g) Got the summation of steps (d), (e), and (f) and annual peak discharge.

The formula for least-square line is as follows:

$$X = A + B\log.\log T/T - 1$$

where

$$A = \Sigma x/N - B\ \{\Sigma z/N\}$$

$$B = \frac{\sum XZ - \sum Z\{\sum X/N\}}{\sum Z^2 - (\sum Z)^2 / N}$$

Discussion

According to the steps mentioned above, the magnitude of floods has been computed for the discharge site Lalganj which lays along the Gandak River. The computed values are presented in the Table 3:

The estimated magnitude of flood discharge of 24529.40, 20687.26, 19028.60, 17363.86, 11636.80, 8934.39, and 4414.13 cumecs are expected to occur in 1000, 200, 100, 50, 5, 2, and 1.01 years, respectively. The same may be translated into their probabilities which are equivalent to 0.1, 0.5, 1, 2, 20, 50, and 99% for Lalganj site. This estimation is based on the 33 years (from 1981 to 2013) sampled data of annual peak discharge in the Gandak basin at Lalganj site. For 95% probability (chances of return period −1.05 years) is 5405.98 cumecs according to this method.

Pearson Type III Distribution Method

In Pearson type III method, to fit the recurrence intervals and skew coefficients distribution, firstly, annual peak floods are transform to

Table 3 Flood frequency analysis of Gandak River at Lalganj: V.T. Chow's method (1981–2013)

Return period T (year)	Probability P (in %)	Log log (T/T−1)	Estimated flood flow (x) = 6071.942165-5490.025864 log log (T/T-1) (cumec)
1000	0.1	−3.3620	24529.40
200	0.5	−2.6622	20687.26
100	1	−2.3600	19028.60
50	2	−2.0568	17363.86
10	10	−1.3395	13426.04
5	20	−1.0136	11636.80
2	50	−0.5214	8934.39
1.2500	80	−0.1555	6925.87
1.0526	95	0.1213	5405.98
1.0101	99	0.3020	4414.13

logarithmic values and then the mean, standard deviation, and skewness coefficient are computed. The steps of computations by this method are as follows:

Procedures

(a) Calculated the mean as $\overline{X}$,
(b) Got Deviation form mean as $X - \overline{X}$,
(c) Calculated $(X - \overline{X})^2$ and $(X - \overline{X})^3$
(d) Calculated standard deviation as:

$$S = \left(\frac{N}{N}\mu^{\wedge 2}\right)1/2,$$

(e) Computed the coefficient of skewness by the following equation:

$$y^{\wedge 1} = \left(\frac{N^2}{(N-1)(N-2)}\mu^{\wedge 3}/\mu^{\wedge 2}\right)3/2,$$

(f) Determined frequency factor 'K' corresponding to the computed value of $y^{\wedge 1}$ and selected probability (P),
(g) Computed the value Ks,
(h) Added $\overline{X}$ to get the required magnitude of flood.

Discussion

Flood frequency results of the Gandak River at Lalganj discharge site by Pearson type III distribution method have been presented in Table 4. For 200 and 100 years, the maximum probable annual peak flood discharges are as high as 20215.14 cumecs and 18574.78 cumecs, respectively. The conversion of their chances in percentage is equal to 0.5 and 1, respectively. With 99 and 95% of probability, it comes down to 6081.36 cumecs and 6364.74 cumecs, respectively.

Foster Type III Method

Foster adopted the use of Pearson's skew functions for fitting observed flood data. The steps of computation of flood frequency analysis by the Foster type III method are hereunder:

Procedures

(a) Found out the mean as $\overline{X}$,
(b) Got Deviation form mean as $X - \overline{X}$,
(c) Calculated $(X - \overline{X})^2$ and $(X - \overline{X})^3$,
(d) Calculated standard deviation as $s = \sqrt{\Sigma \Delta x^2/N}$,
(e) Computed the coefficient of skewness $Cs = \Sigma x^3/(N)s^3$,
(f) For Foster type III curve, found: $\overline{Cs} = Cs\ (1 + 8.5/N)$,
(g) Determined frequency factor 'K' corresponding to the computed value of $\overline{Cs}$ and selected probability (P),

Table 4 Flood frequency analysis of Gandak River at Lalganj: Pearson type III method (1981–2013)

Return period (Years)	Percent chance	Skewness coefficient	K from Appendix *C* for	Ks (2724.846768)	X = 9343 + Ks (in cumec)
200	0.5	1.6	3.990	10872.14	20215.14
100	1	1.6	3.388	9231.78	18574.78
50	2	1.6	2.780	7575.07	16918.07
10	10	1.6	1.329	3621.32	12964.32
5	20	1.6	0.675	1839.27	11182.27
2	50	1.6	−0.254	−692.11	8650.89
1.2500	80	1.6	−0.817	−2226.20	7116.80
1.0526	95	1.6	−1.093	−2978.26	6364.74
1.0101	99	1.6	−1.197	−3261.64	6081.36

(h) Computed the value Ks,
(i) Added $\overline{X}$ to get the required magnitude of flood.

Discussion

The Table 5 displays the flood frequency analysis of the Gandak River at Lalganj site. The probable discharge of 12144.34, 11049.40, 9632.14, 9196.06, and 8873.74 cumecs are expected to happen with the recurrence interval of 1000, 100, 5, 2, and 1.01 years. The translations of the same into chances of occurrence in percentage are 0.1, 1, 20, 50, and 99, respectively. With 95% chances of probability, the expected peak discharge comes down to 8892.70 cumecs at this site.

Summing-up Different Methods

Five methods of flood frequency analysis have been discussed above to estimate the annual peak floods. All these five methods have been used for the same annual peak discharge data of the Gandak River at Lalganj discharge measuring site. The results by different methods of flood frequency analysis for annual peak discharge have been complied in Table 6. The same is presented on a semilogarithmic probability graphical paper in Fig. 3. All these are studied based on the empirical data analysis. It is presumed that the data is the representation of the peak discharges for a very long duration, and

Table 5 Flood frequency analysis of Gandak River at Lalganj: Foster type III method (1981–2013)

Recurrence interval (year)	Percent frequency	Factor K	Ks (s = 474)	Mean $\overline{X}$ (cumec)	Magnitude of flood x = $\overline{X}$ +Ks (cumec)
1000	0.1	5.91	2801.34	9343	12144.34
100	1	3.60	1706.40	9343	11049.40
5	20	0.61	289.14	9343	9632.14
2	50	−0.31	−146.94	9343	9196.06
1.25	80	−0.78	−369.72	9343	8973.28
1.05	95	−0.95	−450.30	9343	8892.70
1.01	99	−0.99	−469.26	9343	8873.74

Table 6 Comparison of flood frequency analysis obtained by different methods: Lalganj (1981–2013)

Return period (in years)	Probability (P) in %	Gumbel's method	Log-normal method	V.T. Chow's method	Pearson type III method	Foster type III method
1000	0.1	24822.58	13335.25	24529.40	'K' N.A.	12144.34
200	0.5	20905.89	'K' N.A.	20687.26	20215.14	'K' N.A.
100	1	19215.12	17436.25	19028.60	18574.78	11049.40
50	2	17518.09	'K' N.A.	17363.86	16918.07	'K' N.A.
10	10	13504.11	'K' N.A.	13426.04	12964.32	'K' N.A.
5	20	11879.83	11414.00	11636.80	11182.27	9632.14
2	50	8925.28	8961.50	8934.39	8650.89	9196.06
1.2500	80	6877.83	7054.00	6925.87	7116.80	8973.28
1.0526	95	5267.18	5609.75	5405.98	6364.74	8892.70
1.0101	99	4322.47	4601.50	4414.13	6081.36	8873.74

'K' N.A. = Frequency factor 'K' is not available

hence, it is normal. The observed behavior of the recorded peak discharges will keep on occurring in the nature even in the years yet to come. All these are probabilistic and not of any kind of certainty. The probabilistic approach is quantified based on certain assumptions of naturally occurring flood trend and behavior.

Flood Frequency Analysis and Flood Management

Flood frequency analysis by different methods gives an insight about the hydrologic characteristics of the river basin. In fact, flood is an outcome of numerous factors related to the shape, size, slope, nature of soil, amount of water, distance to be traveled by water, vegetation, human activities, and interferences of mankind with area pertaining to hindrances in the flow like road, bridges, embankments, barrages, dams in the basin. The amount of sediment load in a river system is also a function of many factors. When the highly charged sediment loaded water is channelized in the plain from the mountainous catchment, it leads to many vicious problems. Therefore, all the aspects concerning the flood must be tackled seriously in a systematic manner. It needs to bridge and block the loopholes which lead to flooding. It is not only applicable to the Gandak River basin, but it must be followed for all the rivers on our earth. These are the basic principles of managing the flood. Area and basin-specific flood creating genesis must be identified first, and systematically, they should be taken care one by one but simultaneously as well.

The above-mentioned five methods of flood frequency analysis help us in knowing as to how much maximum discharge is expected to come. By knowing the discharges for different return periods, one can go for planning different flood controlling engineering structures. If the peak discharges for a particular site in the mountainous catchment are taken to analyze, it may help in designing the dam construction in the area concerned. It needs to take care of the discharge which may happen in certain return period. In the same manner, it also helps in determining the spacing between two embankments in the lower reach of the river. Delaying the water to flow from the source region is one of the best suitable methods of flood control. It helps in recharging the underground water and reducing the runoff. Underground water is again helpful to extract for various uses. For this good forest cover, check dams, improved agricultural practices, judicious land use management are the key factors. Building construction activities are completely banned in the flood line area in the riverbed. National Green Tribunal always looks after the

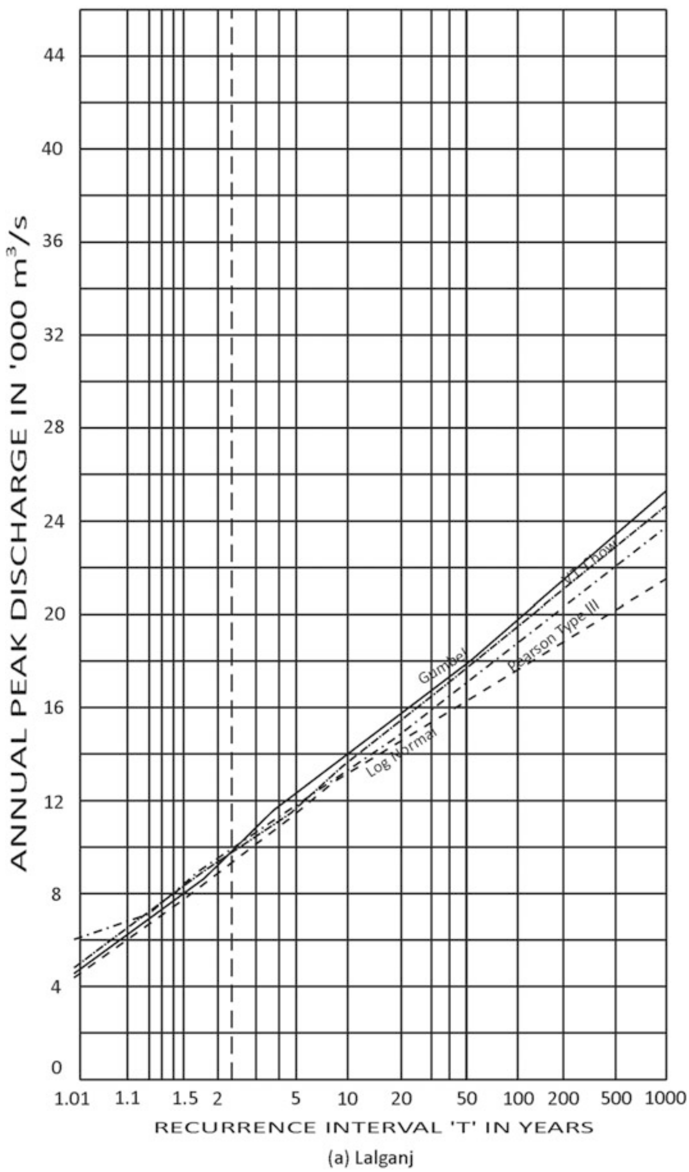

Fig. 3 Flood probability analysis at Lalganj site

environmental issues. Its approval is needed before any developmental activities are initiated. If it is agreed upon wholeheartedly, many of the human generic problems may be minimized and it is also for the benefit of the overall societal development. Therefore, everything must be taken care in appropriate manner for the overall well-being.

Conclusions

Flood in the Gandak River basin is the result of heavy rainfall and snow melt in the mountainous catchment. Huge sediment is one of the important causes of mega fan building at the foothills. Heavily loaded sediment with water discharge chocks the channels on the flat slope in the plain. Chocked channels have lesser carrying capacity of water and solutes. This leads to channel avulsion finally leading to shift in the course of river in a bigger span of time. This is also a cause of hardship to the people in its lower basin. Five methods of peak discharge analysis to estimate the recurring flood have been used in this paper. They are (i) Gumbel's extreme value distribution method, (ii) log-normal method, (iii) V.T. Chow's method, (iv) Pearson type III method, and (v) Foster type III method. These methods are helpful in knowing about the probable discharge for a given return period. The knowledge about this helps our civil engineers to plan different measures in river monitoring actions. The crux of flood reduction and mitigation measures is to manage the human activities in an integrated manner and hence achieve everything in the best suitable way. This ideal management must be translated into action in real life and followed by every human being—all inhabitant, all policy makers, and the concerned in implementing the same.

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