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R.B. Singh
Pawel Prokop
Editors

Environmental Geography of South Asia

Contributions Toward a Future Earth Initiative

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Preface

South Asia is a distinct geographical region with an incredible diversity of natural environment having the world's highest mountain belt – the Himalayas of India, Pakistan, Nepal, and Bhutan – stretching along the entire northern border of the region. The region comprises the Himalayas, the alluvial plains of the Indus and Ganga–Brahmaputra river systems, and the uplands of the Deccan Plateau in India, together with the central hill massif of Sri Lanka. The region is surrounded in the south by three marine ecosystems: the Arabian Sea, the Indian Ocean, and the Bay of Bengal. The seasonal alteration of atmospheric flow patterns between land mass and sea, associated with the monsoons, frequently cause severe floods, droughts, and mass movements over large areas of South Asia. Although the region occupies only 4.8 % of the world's total land area, it has a population of 1.67 billion (23.8 % of the world's total), growing at the rate of 1.8 % per annum. Thus, vulnerable natural features of environment combined with the high population density, rapid economic development, and corresponding competition for agricultural and urban land as well as water resources have enormous societal consequences. The effects of these natural–human interactions are not limited only to the South Asian region but have an impact on environment and society on a global scale.

This book on the environmental geography of South Asia comprises a selection of papers presented at the session on the natural environment, climate change, disasters, and their impact on human society in South Asia during the International Geographical Union (IGU) Regional Conference, held in Krakow, Poland, 18–22 August 2014. The conference was organized by the Institute of Geography of the Polish Academy of Sciences and seven other geographical research institutions in Poland. A few invited papers are also included here to cover all dimensions of environmental geography. The book consists of 19 chapters that contribute to better recognition and understanding of rapid civilization development in the context of both regional and global environmental changes. Thus this volume integrates attributes relating the past, present, and future of South Asia broadly based on biophysical and human dimensions in spatio-temporal perspectives. Climate change, spaceborne monitoring, and mitigation of natural hazards are considered vital components in the context of environmental issues, especially in observation and prediction of extreme climate events, land-use changes leading to land degradation, and urbanization. The contributions range from traditional field techniques and conventional data collection to the use of remote sensing and geographic information systems.

We hope that the present volume will deepen the awareness of numerous changes in both natural and human systems that significantly influence the present and future well-being of South Asian societies in general. The increasing importance of interdisciplinary research is the best tool to combine the different approaches with knowledge and techniques from particular branches of geography. We believe that the book will also be beneficial to people in other fields such as geology, ecology, environmental sciences, tourism, disaster management, and urban studies. We hope, that this volume stimulates further research and that these topics will continue to be focal points for future geographical research at global, regional, and national levels.

We would like to thank the IGU officers and the members of the Conference Organizing Committee. We appreciate the hard work of the contributors and referees of the papers both for their time and their early responses. We are also thankful to Dr. Ajay Kumar for providing assistance. We wish to express our deepest thanks to Ms. Taeko Sato from Springer Japan for all the help provided in the publication process of this book.

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Introduction

Chapter 1
Disaster Mitigation and Management and Importance of Earth Observation

Anupam Anand and Jyotheshwar Nagol

Abstract Natural events such as earthquakes, floods, hurricanes, tsunamis have occurred throughout Earth's history. These are caused by naturally occurring processes and are considered natural hazards and disasters because they negatively affect humans and destroy livelihoods. On the other hand, technological disasters like oil and chemical spills, pollution, industrial accidents, and massive automobile, train, or airplane accidents, are direct results of human activity.

In recent times, occurrence of geologic and hydrometerological events have increased in frequency and intensity exposing ecosystems and local communities to unprecedented hazards. In India, increasing number of floods, landslides, and droughts are causing much loss of life and property. Population growth and intensifying land-use practices are exacerbating the impacts of these hazards. Earth observation is emerging as an invaluable tool for disaster management, providing inputs for risk and vulnerability assessment, early warning systems, and damage assessment and is most informative and effective when partnered with local expertise.

In this paper we elaborate the use of earth observation systems as tools to aid in disaster mitigation, preparedness, response and recovery in India. By earth observation systems we mean the use of remote sensing and allied technology which enables us to observe the dynamics of the earth's surface. We use specific examples and best practices from across the globe to illustrate its applicability in natural disasters with special reference to India.

Keywords Earth observation • Disaster management and mitigation • South Asia • Remote sensing

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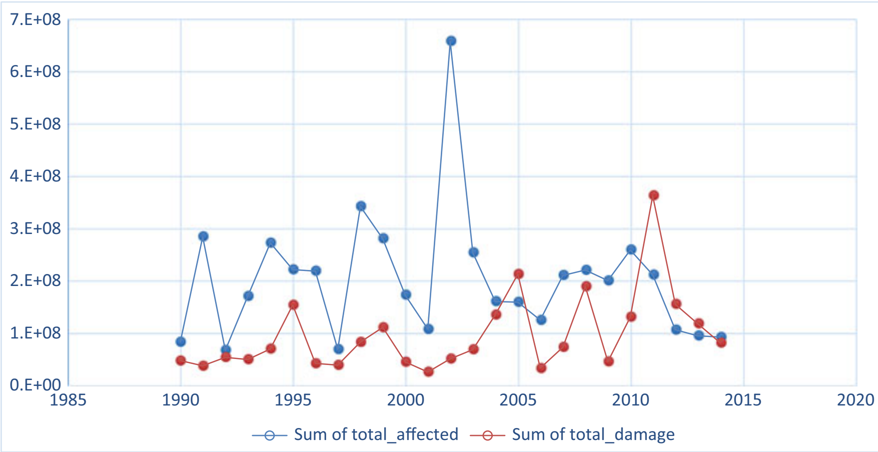

Fig. 1.1 Global figures of human and material loss over 1990. The data was filtered using Centre for Research on the Epidemiology of Disasters (CRED) dashboard

1.1 Introduction

The frequency and intensity of extreme climatological events are increasing globally (Guo 2010) (Fig. 1.1). The unprecedented magnitude of these events expose ecosystems and local communities to hazards to which they are not adapted (ADRC 2012). In order to minimize the effect of the damage, accurate information on the spatial extent and severity of the damage is required for disaster mitigation and management. Earth observation through space-borne, and airborne remote sensing platforms can play a vital role in development of disaster mitigation strategies as well as management by aiding damage assessment and in evacuation planning.

1.2 Disaster Types and Their Global Trend

The spatial distribution of the global disasters varies by their type and origin. The three major categories of disasters by origin are hydrometeorological, geological and biological. The major natural disaster types are drought, flood, wind storm, epidemic, landslide, volcano, extreme temperature, earthquake and tsunamis, insect infestation and wild fire.

As per EM-DAT: The OFDA/CRED International Disaster Database, between, the year 1991–2005, among the ten major types of disasters, flood (32 %) events were the highest, followed by wind storms (25 %), epidemics (13 %) and earthquakes and tsunamis (8 %). When classified by origin, the occurrence of hydrometeorological disasters was highest (76 %) followed by biological disasters (14 %) and geological disasters (10 %). The recurrence biological disasters were the least in all regions except in Africa. In Africa, biological disaster events were more than 12 times the number of disasters of geological origin. A major proportion of these biological disasters were epidemics (38 %).

Asia had the largest number of natural disasters (37.41 %) whereas Oceania had the least (5.53 %). The fatalities reflect the same trend. The largest number of affected (82.21 %) people was in Asia and the lowest (0.60 %) in Oceania (Cvetkovic and Dragicevic 2014).

1.3 Disasters in India

India is one of the most disaster prone countries. India's unique geo-climatic location, high population densities, poor infrastructure, poor-building codes along with high degree of socio-economic vulnerability makes it susceptible to natural disasters. In recent times India has experienced accelerating variability in rain and snow-fall resulting in flash floods, landslides, and droughts – causing much loss of life and property (Table 1.1). Population growth and intensifying land-use practices and climate change exacerbate these changes. Flood in the Srinagar Valley in September 2014, is a recent case. During the event, incessant rains led to the submergence of Srinagar city with some areas submerged under 20 feet of water. Many quarters of the administration, media, and scientific community ascribed the extreme precipitation to climate change. However, the loss of lives and infrastructure have been blamed on unstainable and improper land development, in this case, the encroachment of the local wetland system (Basu 2014). This disrupted the water flow and destabilized the hydrological system of the area.

Data on disasters in India, from the last 15 years show that, amongst the natural disasters, flood events were the most frequent, followed by storms and landslides (Fig. 1.2). Earthquakes and extreme temperatures also feature among the major

Table 1.1 Year-wise damage caused due to floods, cyclonic storms, landslides etc. in India

Year	Live lost human (in no)	Cattle lost (in no)	Houses damaged (in no)	Cropped areas affected (in lakh hectares)
2001–02	834	21,269	346,878	18.72
2002–03	898	3729	462,700	21.00
2003–04	1992	25,393	682,209	31.98
2004–05	1995	12,389	1,603,300	32.53
2005–06	2698	110,997	2,120,012	35.52
2006–07	2402	455,619	1,934,680	70.87
2007–08	3764	119,218	3,527,041	85.13
2008–09	3405	53,833	1,646,905	35.56
2009–10	1677	128,452	1,359,726	47.13
2010–11	2310	48,778	1,338,619	46.25

Source: Ministry of Home Affairs (MoHA), Compendium Environment Statistics India 2013 disasters. In the following sections, we discuss four major natural disasters that occur in India: flood, cyclone, landslide, and earthquake.

1.3.1 Flood

India is one of the most flood prone countries in the world because of its climate and natural environment, namely, the monsoon, silted river systems and the steep, and unstable, erodible mountains slopes, particularly those of the Himalayan range. The average rainfall in India is 1150 mm, but it varies across the country. Most floods occur during the monsoons and are usually associated with tropical storms or depressions. More than 60 % of the states and union territories in India are subject to floods and 40 million hectares of land, roughly one-eighth of the country's geographical area, is prone to floods (MoHA 2015). India's legacy of settlement, construction and development in floodways and floodplains further aggravates the problem. Therefore, it is not surprising that flood events frequently become natural disasters in India (Fig. 1.2). Floods in India have caused loss of both human life and livestock, destruction of property and loss of valuable crops (Table 1.1). Floods have also triggered the outbreak of serious epidemics, specially malaria and cholera. Flood events are also accompanied by scarcity of fresh water and has detrimental effect on crop yields.

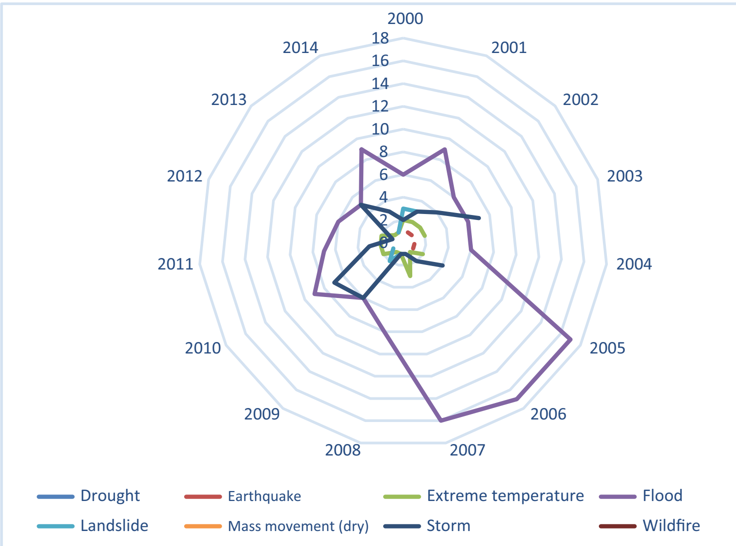

Fig. 1.2 Spider diagram of type and frequency of natural disasters: 2000–2014 (Source: CRED)

1.3.2 Cyclone

A cyclonic storm is accompanied by severe winds, heavy rainfall, storm surges and river floods. These events makes the coastal areas vulnerable to damage. Cyclones are the major natural disasters affecting India's 7516 km, coastline on a regular basis. Nearly 10 % of the world's tropical cyclones occur in India (MoHA 2015). About 71 % of cyclones affects the ten states of Andhra Pradesh, Goa, Gujarat, Karnataka, Kerala, Maharashtra, Orissa, Puducherry, Tamil Nadu, and West Bengal. The islands of Andaman, Nicobar and Lakshadweep are also prone to cyclones. On an average, about five or six tropical cyclones form in the Bay of Bengal and the Arabian Sea hit the coast every year, out of these, two or three are severe (MoHA 2015). The Orissa super cyclone with winds of up to 250 km/h in 1999 was one of the worst cyclones in the country and was responsible for as many as 10,000 deaths.

1.3.3 Landslide

Landslides mainly affect the Himalayan region, the Western Ghats and the Nilgiri range of India. It is estimated that 30 % of the world's landslides occur in the Himalayas (MoHA 2015). The young-fold Himalayan Mountains, with its series of unique curvilinear parallel folds stretched for a total of 3400 km have a long history of landslides. Excessive rains also trigger landslides in the Western Ghats and the Nilgiris. They constitute a major natural hazard and cause considerable loss of life and damage to communication lines, human settlements, agricultural fields and forest lands.

1.3.4 Earthquake

Earthquakes are caused by underground rocks breaking or fracturing under stress caused by movement of continental and oceanic plates. The Indian sub – continent situated on the boundaries of two continental plates, the Indian and the Eurasian plates, is very prone to earthquakes. According to latest seismic zoning map released by the Bureau of Indian Standard (BIS), over 65 % of India is prone to earthquakes of intensity Modified Mercalli Intensity Scale (MSK) VII or more. Earthquakes over 5.5 magnitude on the Richter scale are progressively damaging to property and human life. The entire Himalayan Region is considered to be vulnerable to high intensity earthquakes of a magnitude exceeding 8.0 on the Richter scale.

India has been divided into four seismic zones according to the maximum intensity of earthquake expected. Of these, Zone V is the most active which comprises the whole of north-east India, the northern portion of Bihar, Uttarakhand, Himachal Pradesh, Jammu &Kashmir, Gujarat and Andaman & Nicobar Islands. Many highly populous cities are in these states and the infrastructure and building in these cities are not earthquake resistant.

1.4 Pressing Issues for Disaster Management and Mitigation

The international scientific community is reaching a growing consensus that global climate change is increasing the frequency and intensity of locally extreme climatological events (Guo 2010). Observations during the last decade and projections indicate that extreme events i.e. heat waves, cold waves, floods, droughts, intense cyclones and flash floods will increase. There is thus an urgent need for a paradigm shift in disaster preparedness, mitigation and management strategies.

Although disasters affect all sections of society, poverty can considerably hinder the recovery process. In India where poverty is widespread and as per 2011–2012 data, more the 20 % of the population is below poverty line (Reserve Bank of India 2013). Livelihoods in rural areas are often inextricably linked to environmental resources, thereby increasing the risk and exposure to disasters, in particular those related to floods, fires, earthquakes, droughts and landslides. Poverty also compels people to move and live at physically vulnerable locations, often on marginal land and in unsafe, make shift dwellings vulnerable to structural damage. During a disaster event, many people don’t evacuate for several reasons, including but not limited to, immobility, lack of transportation, limited social capital, weak social networks and the lack of alternative places to move to.

Disasters are unforeseeable by nature, making it is difficult to predict the time and intensity of their occurrence. The vulnerable geo-climatic location and socio-economic context makes India more susceptible. Wide gaps in knowledge, skills and expertise exists among emergency management personnel in India. The Bhuj earthquake in Gujarat state in 2001 and the tsunami of 2004 accentuated the need for a multi-dimensional strategy involving diverse scientific, engineering, financial and social processes in reducing risks from natural disasters (Ahmad and Murli 2012). The following section briefly describes the institutional layout of disaster management in India.

1.5 Disaster Management in India

“Disaster management in India has evolved from an activity-based reactive setup to a proactive institutionalized structure; from single faculty domain to a multi-stakeholder setup; and from a relief-based approach to a ‘multi-dimensional pro-active holistic approach for reducing risk’” (MoHA 2015, pp 55). The Disaster

Management (DM) Act, 2005 provides for the effective management of disaster and related issues in India. The institutional structure for disaster management in India set up under this Act, is in a state of transition and continues to evolve. At present, The National Disaster Management Authority exists at the Centre along with the National Crisis Management Committee, which is part of the earlier setup. The State Disaster Management Authorities (SDMAs) under the Chairmanship of the Chief Ministers and District Disaster Management Authorities (DDMAs) under the Chairmanship of Collectors/District Magistrates/Deputy Commissioners are gradually being formalized. Within this transitional and evolving setup, disaster management have become decentralized in its functions and operates at four levels – Centre, state, district and local. All these agencies and the nodal ministries function under the overall guidance of the Ministry of Home Affairs.

The DM Act, 2005 also provides for the setting up of the National Disaster Response Force (NDRF) constituted by up-gradation/conversion of eight standard battalions of Central Para Military Forces i.e. Border Security Force (BSF), Indo-Tibetan Border Police (ITBP), Central Industrial Security Force (CISF) and Central Reserve Police Force (CRPF). The NDRF is a specialist force trained to respond to the Chemical, Biological, Radiological and Nuclear (CBRN) calamities besides natural calamities. In addition to these agencies, there is National Fire Services, Civil Defense and the Home Guards who works for disaster management related activities in the country.

The Indian government aims to make its disaster management multi-disciplinary and multi-sectoral in approach. India's disaster management frameworks therefore include institutional mechanisms, early warning systems, disaster prevention, preparedness and response and human resource development.

India's evolving disaster management strategy is also integrating data from space-borne and airborne Earth observation systems with ground infrastructure to enhance preparedness, mitigation, management, and post disaster damage assessment. The Disaster Management Support (DMS) Programme (ISRO-DMSP) of the Department of Space (DOS) is using earth observation technology using data from satellites such as Meteosat and INSAT for disaster management in the country. However, disaster management agencies in India need to leverage on the availability of other global datasets available from various international agencies.

1.6 Earth Observation for Disaster Mitigation and Management

Today, earth observation is a critical component of disaster mitigation and management.

Governments across the world have been working to integrate it into their response and management strategies. There is a growing interest in inter-governmental, bilateral and multilateral cooperation to providing EO solutions.

Agencies such as the European Space Agency (ESA), National Aeronautics and Space Agency (NASA), German Aerospace Center (DLR), Indian Space Research Organization (ISRO), Japan Aerospace Exploration Agency (JXA), United Nation (UN) and even private for profit organizations like Digital Globe and Google among others, are more and more willing to share data.

However, gaps between the science of earth observation, policy, and disaster management still remains. Strengthening partnerships based on existing mutual interests and a more integrated approach can provide an alternative and potentially more robust strategy for disaster risk reduction. Dedicated effort has been made by the international community to bridge the gap between the remote sensing community and social and political decision makers in developing countries. One such example is the United Nations Platform for Space-based Information for Disaster Management and Emergency Response (UNSPIDER).

The primary focus of initial disaster response is to repair and reestablish transportation and communication networks, which is then followed by immediate rescue operations. It involves identification of emergency response routes, debris blockages, and collecting information about collapsed buildings, areas of human congregation, topography, and flood hazards, to provide comprehensive logistical support to relief efforts. Data from a combination of space-borne and airborne assets can therefore be invaluable. Multi-temporal and multi-resolution EO data from various platforms can also help plan, execute, and monitor disaster recovery. It can be applied at three hierarchical levels, (1) Regional, (2) Neighborhood and (3) Object level. At regional level, moderate resolution imagery provides a snapshot for early impact assessment. At neighborhood level, analysis of high resolution imagery can help locate the specific areas that were impacted. At the household level, individual structure and extent of damage can be assessed (Exelis 2013).

The common analysis techniques used in disaster studies are feature extraction, change detection, classification, use of indices and anomaly detection (Exelis 2013). In the following section we elaborate how EO data from different satellite systems can be used for disaster mitigation and management together with Geographic Information System (GIS) platforms. We mostly focus on free or easily available datasets here.

1.6.1 Moderate Resolution

The moderate resolution satellite data provides a synoptic view of a larger area. Sensors such as Moderate Resolution Imaging Spectroradiometer (MODIS) have high overpass frequency therefore the data they provide is particularly useful for early detection, warning and characterization of hazards and disasters. Moderate resolution satellite data is useful in disaster response and damage assessment due to fire, flood, oil spills, and volcanic eruptions (Brakenridge and Anderson 2006; Hu et al. 2003; Tanpipat et al. 2009; Wright et al. 2002). The high temporal resolution of these data also allows a better understanding of the underlying processes thereby aiding in consistent monitoring (Sakamoto et al. 2007). For example near real-time images available from NASA Rapid Response (http://rapidfire.sci.gsfc.nasa.gov) system.

These datasets have been used consistently and there are standard land cover, biophysical, atmospheric and fire products available which make it even more easily accessible to end-users of geospatial data (Huete et al. 2002; Justice et al. 2002; Morisette et al. 2002). Spectral richness of MODIS sensors also enhances discriminability of surface features and processes (Fig. 1.3). This image shows several large active fires and the red outlines indicate areas of high surface temperature associated with fire. The main limitations of these datasets are their course resolution and the effect of atmospheric conditions such as clouds and atmospheric conditions.

1.6.2 Semi-high Resolution

Semi-high resolution satellite data provides better spatial resolution but with less frequent acquisition. Opening up of the entire Landsat archive by USGS has made it the longest freely available continuous global record of the Earth's surface. The Landsat data has its application in assessing earthquakes, tsunamis, fires, floods, oil spills and related disasters (Nourbakhsh et al. 2006; Tanaka et al. 1983; Yusuf et al. 2001). This has enabled the scientific community to be able to develop

Fig. 1.3 NASA MODIS satellite imagery of smoke plumes coming out of active wildfires in New South Wales, Australia (Source: Land Atmosphere Near real-time Capability for EOS (LANCE))

globally consistent standard products which include land cover maps and maps of vegetation indices such as NDVI (Kim et al. 2014; Sexton et al. 2013). The Landsat data combined with elevation data from Shuttle Radar Topography Mission (SRTM) has been widely used to assess the structural damage (Tanaka et al. 2005). Figure 1.4 demonstrates the use of visible and derived vegetation indices from Landsat data to assess the extent of flood damage. Negative NDVI values are indicative of areas of higher water accumulation. It has also enabled development of tools such as Openforis (http://www.openforis.org/), CLASlite and Global Forest Watch tool (Asner et al. 2009; Watch 2002) to help policy makers.

Apart from U.S. agencies, European, Japanese and Indian space agencies have also opened their data archives of semi-high resolution satellite data for disaster management. The Sentinel 2 series from European Space Agency (ESA) is specifically built to support disaster management (Drusch et al. 2012). The Sentinel system also provides support in the Asian region using an integrated decision support system (Asia 2010; Kaku et al. 2006). The Resource Sat series of satellites from ISRO have been used to map and model the flood hazard zones in India and for landslide assessment. The semi high resolution HJ-1A and HJ-1B satellites have

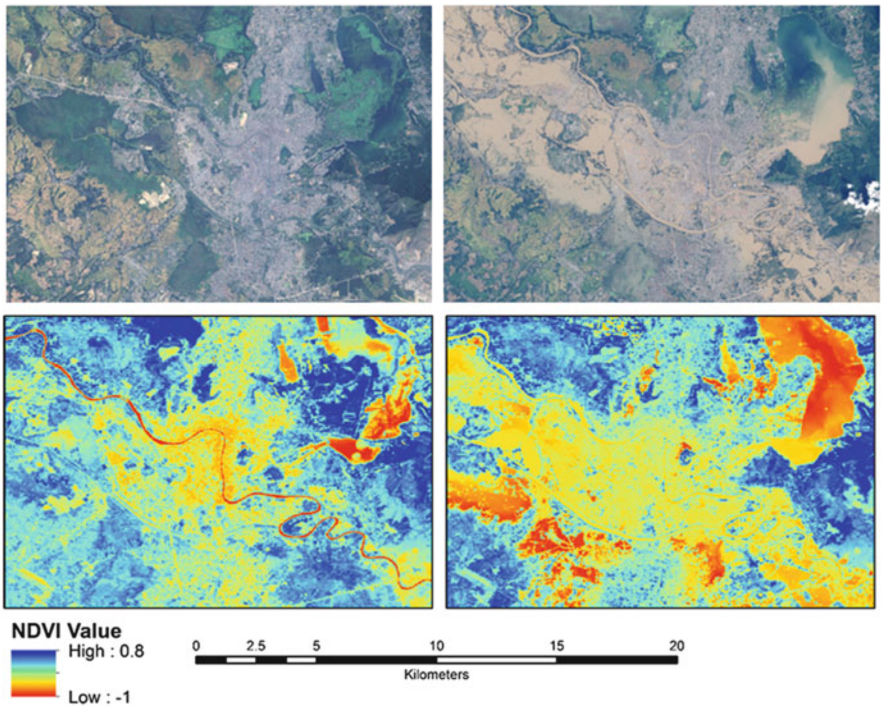

Fig. 1.4 Srinagar floods, 2014. *Top-left* – Landsat 8 RGB before floods; *bottom-left*: NDVI image before floods; *top-right* – Landsat 8 RGB after floods; *bottom-right*: NDVI image after floods. Large areas of water accumulation can be seen in the visible as well as NDVI image on the right associated with low NDVI values

suite of sensors to monitor the disaster in all weather conditions (Wang et al. 2010). The limitation of these datasets is that they have low temporal and spectral resolution and limited scope in changing the acquisition strategy.

1.6.3 High Resolution Satellite Systems

High resolution satellite data have the capability to provide accurate description of disaster events and are very helpful in both management and mitigation of disasters. In recent decades there has been a rapid increase in availability of high resolution satellite data. Many commercial satellite systems are now readily accessible and easy to disseminate. Some of the popular sensors are World View, GEOEYE, and IKONOS etc. Commercial systems such as Worldview-3 can provide data with spatial resolution of 50 cm and up to eight spectral channels (Kruse and Perry 2013). These satellites often provide stereo-pair images which can be used for generating 3-D images which then can be used for volumetric analysis (Aguilar et al. 2014).

Many startup companies have recently launched microsatellites which can provide high resolution imagery on demand at much cheaper rates. Some of these microsatellites such as Skysat 2 and Airbus Pléiades can also provide live high definition video which makes it much more valuable for tracking development in real-time (Airbus 2015; Skybox 2015). It is not an uncommon practice for these commercial organizations to provide free data of disaster hit areas for humanitarian purposes. Data such as this can be very helpful for first responders in their rescue and relief operations. In Fig. 1.5 we can see a high resolution Skysat I imagery freely made available by the ‘Skybox for greater good’. The imagery (Fig. 1.5) shows the Tseri-Phulong Landslide in the Tibet region of China caused by mining activity (Petley 2013).

There are several factors which limit the use of high resolution satellite data. These datasets have limited temporal resolution, are costly and require additional expertise. These data have low spectral resolution therefore the per-pixel classification doesn’t yield high accuracy. In that case the context based ‘object based’ classification is used (Blaschke 2010). There has been a lot of new development in the area of image analysis for these types of data. Moreover the magnitude of these data is much higher when compared to the courser resolution satellite data. Faster object based classification algorithms and cloud based computing are being used to deal with the enormity of data and the need for computational power. In mapping the required information for disaster management, there is no reliable automated feature extraction approaches available yet. Time-consuming visual inspection is still the preferred method and high spatial resolution allows easy interpretation with little expertise and is crucial for management and mitigation.

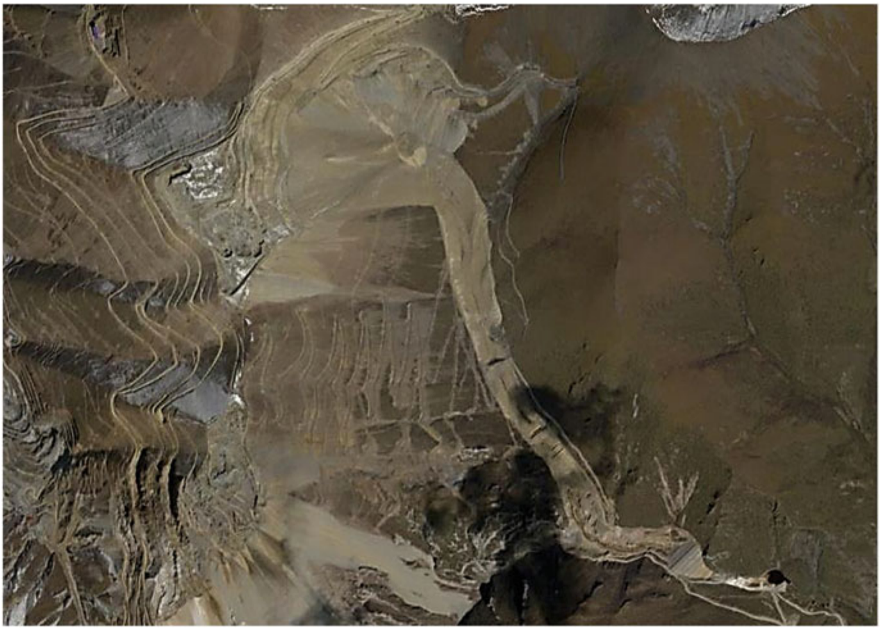

Fig. 1.5 View of the Phulong Valley landslide attributed to the mining activity (Acquired 2014 – 10-06, 03:25:53 GMT, courtesy: Google-SkySat)

1.6.4 Unmanned Aerial Vehicle System

Autonomous and semi-autonomous Unmanned Aerial Vehicle (UAVs), also popularly known as drones, have been primarily used for military applications for past few decades. With decreasing costs of UAV technology, the small UAVs are now being frequently deployed for civilian applications like disaster response (Daniel et al. 2009), precision agriculture (Herwitz et al. 2004; Xiang and Tian 2011), natural resource management (Wallace et al. 2012), rangeland management (Rango et al. 2009), wildlife management (Jones et al. 2006) and environmental research (Thomas et al. 2012).

Fast and flexible survey of disaster zone is a challenge, many disaster response operations have to deal with, on a regular basis. Spaceborne or airborne data although available in many cases, can take days to acquire and can be logistically complex due to cloud cover, inclement weather conditions and safety issues. On the other hand, battery operated, low flying, small scale, man portable drones can provide immediate and even real-time data with little logistical support. Depending on the airframe design and payload configuration these drones can fly for as long as 30 min (http://en.wikipedia.org/wiki/DRDO_Netra; https://www.sensefly.com/drones/ebee.html) to 2 h (http://uav-solutions.com/talon120/). These drones, both fixed wing and multi-rotor systems, are capable of carrying optical or thermal

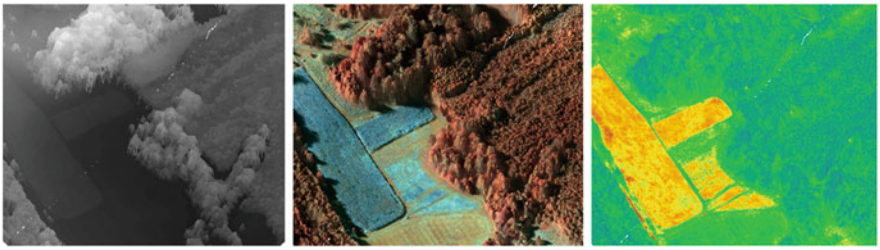

Fig. 1.6 *Left*: digital surface model, *center*: false color image and *right*: NDVI image. These products are derived from data collected through eBee, a small UAV system

cameras (Fig. 1.6, Images at Center and Right) and even the transmitters to telecast the images and video in real time. Because of the autonomous nature of the flight control systems there is little to no flight training required. The images acquired from UAVs can also be converted into 3D model enabling volumetric analysis. This is done using stereo pairs. The images are joined together to yield point clouds which are further converted into 3D surface models (Fig. 1.6, left image).

For most disaster response teams, the area of action is within the range of these low flying man-portable drones. Proper situational awareness provided by these drone based surveys can help appropriate deployment of valuable and limited resources for timely search, rescue and response planning.

In India, drones like DRDO-Netra, a multi-rotor system, are already being used for search and rescue operations and disaster management. For example during 2013 floods in Uttarakhand, India, National Disaster Response Force (NDRF) used drones to locate stranded people using real-time video feed. The major limitation of the UAV system is cost, expertise and lack of regulation which restricts their usage. However, their usage is still growing and becoming integral part of many disaster response strategies.

1.6.5 Active Systems Such as Radar and Lidar and Others

The passive remote sensing systems are limited by atmospheric conditions (Jha et al. 2008). On the other hand, active remote sensing systems like Lidar and Radar are not affected by presence of clouds, and changing atmospheric composition making them more useful during inclement weather and low light and low visibility scenarios. The fact that, majority of disasters are hydro-climatological, the availability of newer technologies such as Lidar becomes much more important. RADAR sensors particularly Synthetic Aperture Radar (SAR) are commonly used sensors for hazard risk management (Buchroithner and Gr'anica 1997). In Fig. 1.7, a radar image acquired by Sentinel-1A through its 'Interferometric Wide Swath' in dual polarization shows the precise extent of flood in Zambezi River, Namibia. Sentinel 1A is the first series of satellites in the Copernicus constellation

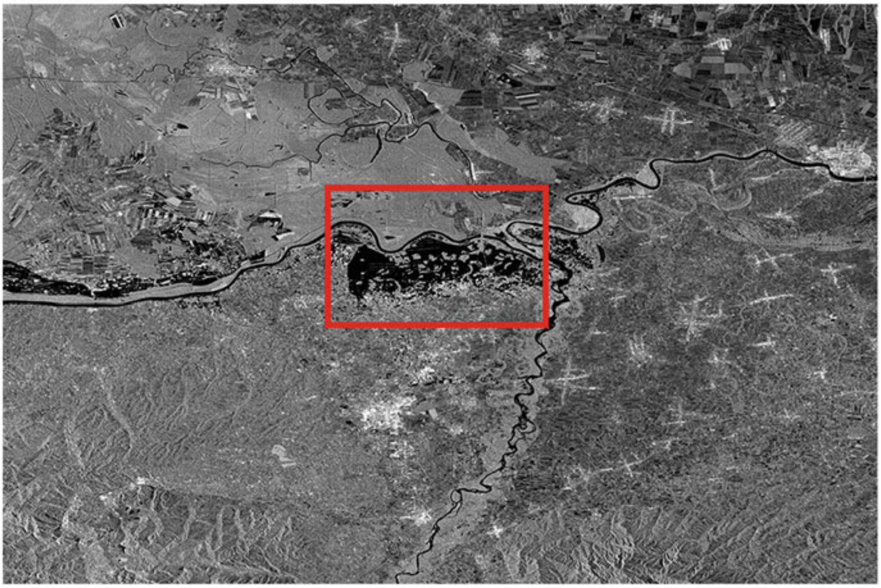

Fig. 1.7 Extent of flooding in the Caprivi plain from the Zambezi River in Namibia (Source: ESA)

launched by the European Space Agency (ESA). The data from this mission is publically available. This kind of information allows authorities to precisely know and better manage crisis situations.

Lately, Lidar data has been widely used for mapping the surface in three dimension (Tralli et al. 2005). This technology is very helpful in estimating the structural damages through high-resolution digital elevation models. However the cost of acquisition of such data limits its usage to developed countries.

Some other sets of satellite systems are also widely used in disaster management and mitigation planning. Ex. The Tropical Rainfall Measuring Mission (TRMM), its follow-up mission, the Global Precipitation Measurement (GPM), a joint mission between NASA and the Japan Aerospace Exploration Agency (JAXA) are designed to monitor and study tropical rainfall. It provides precipitation data at 3-h temporal resolution and at 0.25° spatial resolution. These missions have been a great asset for studying the tropical region.

1.6.6 WebGIS, Social Media and Crowdsourcing

Timely dissemination of information is very crucial in a disaster situation. These days powerful online geospatial analysis and decimation tools are being used to disseminate EO data. These easy to access tools provide a crucial platform for all the stakeholders to share and use EO as well other relevant data.

Social media sites such as Facebook and Twitter are also being used to crowdsource GPS enabled pictures and geo located tweets of disaster events, in order to aid disaster communication, rescue, relief and rehabilitation efforts during natural calamities such as typhoons, earthquakes and fires. With the advanced technology that has become the norm, such as Internet-capable smartphones, with microphones and cameras, their power can be capitalized (Underwood 2010). Crowd sourced data can also be fed into a GIS for integration with EO data and other spatial information to monitor rescue and relief operations during calamities. Google's Crisis Response ("https://www.google.org/crisisresponse/") is one such example which brings the power of earth observation, webgis and crowd sourced information together to bridge the information gap between the crisis managers and affected people.

However, challenges exist in ensuring data quality, identifying, and extracting relevant information from a large volume of crowdsourced data and subsequent real time processing (Goodchild and Glennon 2010). Crowdsourced data can also play an important role in places where media is restricted due to poor economic and governmental restrictions. Apart from technological challenges in processing crowd sourced data, there are also issues of privacy. In spite of this being a new technology and some inherent challenges, crowdsourcing geographic information have helped in disaster response, for example wildfires in the U.S. (Goodchild and Glennon 2010) and disaster relief during the Haitian Earthquake (Zook et al. 2010).

1.7 Summary and Conclusion

There is an international consensus that climate change and its impacts are intensifying globally. Earth observation systems can offer accurate, frequent and almost instantaneous data over large areas anywhere in the world. When a disaster strikes, remote sensing, where available is often the only way to view what is happening on the ground. As discussed before, each satellite carries one or more sensors on board and many of these sensors are useful for disaster monitoring. Thermal sensors can spot active fires, infrared sensors can pick up floods, and microwave sensors (that penetrate clouds and smoke) can be used to measure earth deformations before and during earthquakes or volcanic eruptions.

Although disaster management agencies in India are using available earth observation technologies to aid in the efficient management of natural disasters in the country, there is an urgency for a centralized disaster database which will work in coordination with different agencies, volunteer networks, and local expertise and disaster response personnel on ground. With regards to information dissemination, wide gap exists between disaster management data support systems and emergency managers working in different agencies. Climate change and its' impact is a global emergency and needs to be addressed not only through nationally coordinated efforts but also through global collaborations and resources. India's evolving disaster management strategy with a multi-disciplinary and multi-sectoral approach is a step in the right direction.

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Chapter 2
Exclusionary Urbanisation in South Asia

Debolina Kundu

Abstract Taking eight South Asian countries of Afghanistan, Bangladesh, Bhutan, India, Maldives, Nepal, Pakistan, Sri Lanka as the units of analysis, the study analyzes the level of urbanization, urban people's accessibility to basic amenities and a set of other economic indicators like poverty, unemployment, GDP growth rate, value added by industry etc. The paper begins by over-viewing this debate and goes on to analyse the relationship between urbanisation and economic development and its impact on quality of life and poverty in urban areas. It critically analyses the controversy in the literature, by drawing upon the empirical studies on the subject, focussing on South Asia. A detailed analysis of the pattern of urbanisation in South Asia and correlates of urbanization across different countries has been attempted. It also examines the policies and programmes at the national and regional levels to determine how they are responsible for ushering in an era of exclusionary urbanisation and deceleration in urban growth. The final section summarises the findings of the study.

One can put forward the thesis of exclusionary urban growth in most South Asian countries which is linked with formal or informal denial of entry to the prospective migrants and increased un-affordability of urban space and basic amenities by the rural poor based on an overview of the macro statistics. The spatial scenario of urban growth as projected by UNPD suggests that small and less developed countries in south Asia may record high population growth in their urban centres, but the growth rates have been projected to slow down during the next few decades. These have shown high pace of urbanization and rapid economic growth in recent years, backed up by foreign and domestic investment. Moreover, the structure of urban growth has been top heavy for most of the south Asian countries where a few large cities (million plus) account for a high proportion of urban population. An overview of the pattern of interdependencies among select development indicators suggests that the *level* of urbanization relates strongly and positively with that of economic development, and also with domestic/foreign investment, export base etc. There exists no definitive evidence suggesting that urban growth has resulted in increased access of people to basic amenities like

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drinking water and sanitation to the average people. All these would dampen the pace of urban growth notwithstanding the magnitude of absolute figures of increment that are large due to the pure demographic weight of the region. South Asia is unlikely to go the same way as that of Latin America in the second half of the last century.

Keywords Exclusionary urbanisation • Accentuation • Regional and interpersonal inequality • Globalisation • Structural reform

2.1 Introduction

A commonly held belief among urban scholars is that economic liberalisation and associated structural reform lead to acceleration in the pace of economic growth in less developed countries which in turn result in rapid rural urban (RU) migration, giving boost to the pace of urbanisation. A section of scholars, on the other hand, argue that the process of urban development in less developed world as not necessarily a developmental phenomenon and associate it with accentuation of regional and interpersonal inequality, often resulting in increased poverty.

The fact that over 60 % of world population live in Asia have urged researchers, planners and administrators derive their perspectives on urbanisation based on the absolute magnitudes or magnitudes of change in relation to corresponding global figures (Kundu and Kundu 2010). This has led to quick conclusions and sweeping generalisations regarding Asia experiencing unprecedented urbanisation in recent past or the trend to continue for the next few decades. These generalisations are based on the absolute population figures and the share of the region in global totals that understandably work out to be high. The increments to urban population or net migration also tend to be very high for the region because of the high base year rural and urban population. These unfortunately provide no basis for drawing inference regarding the strength of the forces behind urban development.[1]

Today, more than half of the population lives in urban areas (UNESCAP 2014). Asia, despite its lower level of urbanization (47.5 % in 2014) is home to 53 % of the world's urban population, followed by Europe with 14 % and Latin America and the Caribbean with 13 % (WUP 2014). The 2014 revision of the World Urbanization Prospects by UN DESA's Population Division notes that the largest urban growth will take place in India, China and Nigeria. These three countries will account for 37 % of the projected growth of the world's urban population between 2014 and 2050. By 2050, India is projected to add 404 million urban dwellers, China 292 million and Nigeria 212 million.

Taking into account eight South Asian countries of Afghanistan, Bangladesh, Bhutan, India, Maldives, Nepal, Pakistan, Sri Lanka, the present study tries to

[1] Predictions such as urbanisation has taken long to get underway "but is expected to accelerate dramatically in the 1990s" (Forbes and Lindfield 1997) have proved to be wrong.

analyze the level of urbanization, urban people's accessibility to basic amenities and a set of other economic indicators like poverty, unemployment, GDP growth rate, value added by industry etc. The present paper begins by over-viewing this debate and goes on to analyse the relationship between urbanisation and economic development and its impact on quality of life and poverty in urban areas. The second section of the paper which follows this brief introduction, critically analyses the controversy in the literature, by drawing upon the empirical studies on the subject, focussing on South Asia. A detailed analysis of the pattern of urbanisation in South Asia and correlates of urbanization across different countries has been attempted by incorporating a select set of socio economic indicators within the framework, in the third section. The next section examines the policies and programmes at the national and regional levels to determine how they are responsible for ushering in an era of exclusionary urbanisation and deceleration in urban growth. The last section summarises the major findings of the study.

2.2 Urbanisation and Economic Development: An Overview of the Debate

Increase in investments, both domestic and international in infrastructure and industries, often associated with measures of globalisation and structural reform, backed up by technological advancements in transport and building sectors, are taken to be behind rapid urbanisation. Linking of the cities, particularly the larger ones, with global economy is expected to bring in also inflow of capital from outside the country, accelerating, thereby, the pace of economic growth impacting further on urbanisation since much of the investment and consequent increase in employment have been within or around the existing urban centres. Even when the industrial investment takes place in inland rural settlements, in a few years, the latter acquire urban status. There is thus, a strong linkage between liberalization, investment and economic growth which is expected to accelerate the pace of urbanisation in developing countries (Kundu and Kundu 2010).

A Report of UNFPA/DESA 2008 postulates that "no country in the industrial age has ever achieved significant economic growth without urbanisation" (UNFPA/DESA 2008). It argues further that even when the increase in manufacturing sector is export-based, leading to development of industrial enclaves away from the mega cities, in the long term these become an integral part of the urban segment.[2] Analysing the specific situation in Asian countries, Asian Development Bank (1996) has argued that there is "well established correlation between development and level of urbanisation in Asian

[2] In a similar vein, Cohen (2006) argues that in most cases, high urban growth rate is "an indicator of success rather than failure and most of the world's largest cities are located in countries with the world's largest economies."

region" since the countries that have urbanised rapidly "in the last 10–20 years are generally those with most rapid economic growth".

The opposite viewpoint has also been quite unyielding, although its ability to impact on the development policies has been limited. It sees the cities in the process of getting globally linked not necessarily as "machines for producing wealth" but also for "expanding inequalities". The outcome has been noted to be alarming as the studies point out an increasing trend in the number of urban poor in these cities. Piel (1997) has argued that the world's poor once huddled largely in rural areas have "gravitated to the cities" in the modern world. Ravallion et al. (2007) suggests that it will not be many decades before a majority of the developing world's poor would live in urban areas. Anna Tibbaijuka, Executive Director UN-HABITAT in her keynote address at the Opening Ceremony of the FIG Working Week 2008 argues that "95 % of urban expansion is taking place in those cities least equipped to negotiate the urban transition – the secondary cities of Africa and Asia. As a result we are witnessing the urbanisation of poverty". Overviewing the macro level evidences, Homeless International and Asian Coalition for Housing Rights (2006) have pointed out that around one in every three persons in Asia's cities, live in slums.

Kanbur and Venables (2007) argues that spatial disparities have been high and rising[3] in recent years, specifically in countries like China while analysing spatial inequality been in 58 developing economies, including a few from Asia, over the last two decades. Importantly, spectacular economic growth has been accompanied by growing regional inequality during the period when the countries have seen accelerated urbanisation. The rapid growth in urban population has been attributed to the displaced rural migrants being absorbed within informal urban economy.

The pace of urbanization in Asia and the Pacific has resulted in economic growth but that has also increased the level of poverty within cities – this has been noted in a report from the United Nations for Asia and the Pacific Commission. Releasing the "Statistical Yearbook for Asia and the Pacific" for 2008, Pietro Gennari, chief of ESCAP's Statistics Division observed[4] that current growth of cities is having a "knock-on effect" through erosion of "people's ability to access clean water and sanitation in urban areas. Consequently, "we see more and more people living in slums".

Despite these divergent perspectives, the protagonists of globalization, its critics and 'dispassionate researchers' seem to converge on the proposition that urban growth in the developing countries in the post liberalisation phase would be high. The average rate of economic growth of the Asian countries has also been noted to be impressive – 7 % per annum for over the past half a decade till the global crisis hit them. Even in the worst year of the crisis, 2008–2009, their growth rate declined

[3] One may also mention the spatial disparity in Indonesia by Friedman (2005) and the transition economy of Tajikistan by Anderson and Pomfret (2005), the countries characterised by rapid urban growth.

[4] UNESCAP (2008).

merely by two and a half percentage points, getting the credit for preventing global economic growth going below sub-zero level.

2.3 Urbanisation and Economic Development in South Asia: Implications in Terms of Socio-Economic Deprivation

Level of urbanization shows a secular increase from 2000 to 2010 for each of these eight South Asian countries. Maldives registered the maximum increase in the level of urbanisation over the last decade (about 12 percentage point from 2000 to 2010). In 2010, Afghanistan, Nepal and Sri Lanka reported low level of urbanization as compared to the average of South Asian countries (Table 2.1). Average annual growth rate of urban population during the last decade (2000–2010) shows that urban growth rate is highest in Bhutan followed by Maldives. In contrast, Sri Lanka exhibits least urban growth over the last decade. However, the relatively large countries like India and Pakistan have moderate level of urbanization growth between 2.6 % and 2.7 %.

Urban rural growth differentials (URGD) and rural to urban migration gives a much better picture of urban growth. It is important to note that during the period of 2005–2010, URGD was much higher for small countries like Bhutan and Maldives as compared to any other nation in South Asia. This is mainly because the rural areas of these two countries register a negative growth during the same time period. This can probably be attributed to out-migration from rural areas and its consequent resettlement in the already existing urban areas. For example, in Bhutan, net migration rate was 47 % in urban areas in 2005 (World Bank 2008). URGD (2005–2010) is lowest in India. The pace of urbanization had increased in six south Asian countries (Afghanistan, Bangladesh, Bhutan, India, Maldives, and Pakistan) as the URGD is slightly higher in 2005–2010 as compared to 2000–2005. The only exception is Nepal where URGD declined marginally. Sri Lanka which had a negative URGD in 2000–2005 i.e. rural growth rate is higher than the urban shows a different trajectory in 2005–2010 where the growth rate of rural and urban area exactly matches with each other (Table 2.1).

A size class analysis has been attempted for the countries of south Asia vis-à-vis those of Asia and world based on figures from the World Urbanisation Prospects: The 2014 Revision. Iran has been included in the list of South Asian countries as per this source. Table 2.2 shows that South Asia has a very top-heavy urban structure with 15.3 % of the population living in ten million plus cities as compared to 12 % and 10 % for Asia and world respectively. Bangladesh has the highest share of population in this size class (32.9 %) constituted by Dacca, followed by Pakistan (Karachi) and India. In the next category, which is between 5 and 10 million, 8.4 % of the urban population of south Asia live as compared to 10.3 % for Asia and 8 % for the world. Iran accounts for over 15 % of its urban population in this size class

Table 2.1 Trends in urbanization

Countries	Percentage of urban population			Average annual growth rate of population									
				Urban				Rural	Urban	URGD	Rural	Urban	URGD
	2000	2005	2010	2000	2005	2010	2000–2010	2005–2010[a]			2000–2005		
Afghanistan	21.3	22.9	24.7	4.6	5.0	4.1	4.5	3.4	5.4	2.0	4.2	6.1	1.9
Bangladesh	23.6	26.8	30.5	3.6	4.0	3.6	3.0	1.0	3.5	2.5	1.4	3.5	2.1
Bhutan	25.4	31.0	34.8	7.2	6.5	4.1	5.7	–0.3	4.9	5.2	1.9	5.1	3.2
India	27.7	29.2	30.9	2.5	2.7	2.4	2.6	1.1	2.4	1.3	1.3	2.3	1.0
Maldives	27.7	33.7	40.0	4.1	5.7	5.0	5.6	–0.3	5.3	5.6	1.9	4.0	2.1
Nepal	13.4	15.2	16.8	6.5	3.6	3.2	3.7	1.4	4.9	3.5	1.6	5.3	3.7
Pakistan	33.2	34.7	36.6	3.2	2.8	2.9	2.7	1.2	3.0	1.8	1.5	3.0	1.5
Sri Lanka	18.4	18.4	18.3	0.7	1.0	0.7	0.5	0.5	0.5	0.0	1.0	0.1	–0.9
South Asia	23.8	26.5	29.1	4.1	3.9	3.3	3.5	1.0	3.7	2.7	1.9	3.7	1.8
South and South-West Asia	30.5	32.3	34.3	2.7	2.7	2.5	2.6						
World	46.6	49.1	51.6	2.1	2.3	2.2	2.2						

Source: UNESCAP (2013, 2014)
Note: The figures for South Asia are the arithmetic mean of eight countries mentioned in the list
Note: The figures for South and South-west Asia include the eight counties mentioned in the list as well as Iran, Islamic Republic of and Turkey
[a]World Statistics Pocketbook, 2006 and 2009. Department of Economic and Social Affairs, Series 5, No. 34, United Nations, New York, 2010

Table 2.2 Share of urban population by size class in South Asian countries (2000–2010)

Major area, region, country or area	10 million or more				5–10 million				1–5 million				500,000–1 million				300,000–500,000				Fewer than 300,000	
	Nos.		% Urban		Nos.		% Urban		Nos.		% Urban		Nos.		% Urban		Nos.		% Urban		% Urban	
Year	2000	2010	2000	2010	2000	2010	2000	2010	2000	2010	2000	2010	2000	2010	2000	2010	2000	2010	2000	2010	2000	2010
World	17	23	8.9	10.3	30	40	7.3	8.0	314	373	21.0	20.8	385	487	9.2	9.5	501	628	6.7	6.7	46.9	44.8
Asia	9	13	10.2	12.0	19	27	9.7	10.3	144	181	19.5	18.7	180	248	8.8	9.3	248	328	6.8	6.8	45.0	42.9
Southern Asia	5	5	15.6	15.3	5	6	7.1	8.4	42	59	16.3	19.2	47	56	8.0	7.0	60	79	5.6	5.5	47.4	44.5
Afganistan	0	0	0	0	0	0	0	0	1	1	54.8	53.1	0	0	0	0	0	1	0	5.4	45.2	41.5
Bangladesh	1	1	32.9	32.0	0	0	0	0	2	2	14.6	11.3	1	2	2.2	2.9	2	5	2.2	4.1	48.1	49.7
Bhutan	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	100.0	100.0
India	3	3	15.7	14.9	3	4	6.0	8.2	28	42	16.1	19.6	39	42	9.7	7.8	41	55	5.6	5.6	46.9	43.8
Iran	0	0	0	0	1	1	16.9	15.3	5	7	16.4	20.8	3	6	5.8	7.0	11	10	10.3	7.6	50.6	49.3
Maldives	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	100.0	100.0
Nepal	0	0	0	0	0	0	0	0	0	0	0	0	1	1	20.7	21.5	0	0	0	0	79.3	78.5
Pakistan	1	1	21.0	22.2	1	1	11.4	11.8	6	7	17.7	20.0	2	4	2.5	4.4	6	8	4.9	5.0	42.4	36.5
Sri Lanka	0	0	0	0	0	0	0	0	0	0	0	0	1	1	18.5	18.0	0	0	0	0	81.5	82.0

Source: World Urbanisation Prospects: The 2014 Revision constituted by Tehran only. There is less variation in the cities in the size class 0.5–1 million across nations with the exception of Nepal and Sri Lanka which account for 21.5 and 18 % of the population respectively. In both these countries, the respective capital cities of Kathmandu and Colombo account for this share. The share of South Asia in this size class is low (7 %) as compared to Asia or the world (over 9 %). The size class of 300,000–500,000 account for about 7 % of the world and Asian population. This share is about 5 % for south Asia and other Asian countries except Iran where 10 cities account for around 8 % of the population. In the smallest size class, which is less than 300,000, about 45 % of the world population live. Asian cities account for 43 % as compared to 45 % for South Asia. In the small countries like Bhutan and Maldives, all cities are in this size class accounting for 100 % of the population.

The average annual rate of change of urban population was around 2.2 % for the world as compared to 2.8 for Asia and 2.6 for south Asia as per the World Urbanisation Prospects: The 2014 Revision (Table 2.3). The WUP projects a decline in the growth rates of urban population for all the countries by 2020, except Sri Lanka where the population growth rate is expected to increase marginally during this decade. Smaller countries of south Asia registered higher population growth rate because of the smaller population base.

Bangladesh and Sri Lanka accounted for 18 % of the urban population (Table 2.4). Iran accounts for about 73 % of its population living in urban areas. About 54 % of the world population live in urban areas in 2014. The share is about 48 % in Asia and 34 % in south Asia. India stands close to south Asia average at 32 %. Pakistan and Bhutan stand at around 38 %. Table 2.5 shows the biggest million plus cities across the South Asian countries. India, Bangladesh, Pakistan and Iran account for the maximum number of large million plus cities in South Asia with India having the highest number and share of such cities.

Table 2.3 Level and pace of urbanisation in South Asian countries

Country code	Major area, region, country or area		Average annual rate of change of urban population		
		2000–2005	2005–2010	2010–2015	2015–2020
900	World	2.27	2.20	2.05	1.84
935	Asia	3.05	2.79	2.50	2.10
5501	Southern Asia	2.79	2.59	2.52	2.40
4	Afganistan	5.23	4.17	3.96	3.77
50	Bangladesh	4.12	3.64	3.55	3.19
64	Bhutan	6.79	4.28	3.69	2.89
356	India	2.67	2.47	2.38	2.28
364	Iran	2.32	2.08	2.07	1.78
462	Maldives	5.69	5.20	4.49	3.52
524	Nepal	4.19	3.24	3.18	3.08
586	Pakistan	2.80	2.88	2.81	2.77
144	Sri Lanka	1.07	0.73	0.84	1.11

Source: World Urbanisation Prospects: The 2014 Revision

Table 2.4 Percentage of population residing in urban areas in South Asian countries

Major area, region, country or area	Percentage of urban population		
	2000	2010	2014
World	46.61	51.64	53.6
Asia	37.47	44.77	47.5
Southern Asia	29.06	32.75	34.4
Afganistan	21.28	24.69	26.3
Bangladesh	23.59	30.46	33.5
Bhutan	25.42	34.79	37.9
India	27.67	30.93	32.4
Iran	64.04	70.63	72.9
Maldives	27.71	39.98	44.5
Nepal	13.43	16.82	18.2
Pakistan	33.16	36.60	38.3
Sri Lanka	18.44	18.32	18.3

Source: World Urbanisation Prospects: The 2014 Revision

Table 2.5 The largest urban agglomerations ranked by population size in South Asian countries (1990, 2000, 2010)

Year	Country or area	Urban agglomeration	Population (millions)
1990	India	Mumbai (Bombay)	12.44
		Kolkata (Calcutta)	10.89
		Delhi	9.73
	Pakistan	Karachi	7.15
	Bangladesh	Dhaka	6.62
	Iran (Islamic Republic of)	Tehran	6.36
	India	Chennai (Madras)	5.34
2000	India	Mumbai (Bombay)	16.37
		Delhi	15.73
		Kolkata (Calcutta)	13.06
	Bangladesh	Dhaka	10.28
	Pakistan	Karachi	10.03
	Iran (Islamic Republic of)	Tehran	7.13
2010	India	Delhi	21.94
		Mumbai (Bombay)	19.42
	Bangladesh	Dhaka	14.73
	India	Kolkata (Calcutta)	14.28
	Pakistan	Karachi	14.08

Source: World Urbanisation Prospects: The 2014 Revision

2.3.1 Socio-economic Levels of Development

An attempt is made in this section to analyse the socio-economic levels of development of the South Asian countries and ascertain the pattern of interdependency of the indicators of urban growth and URGD at different periods with those of economic development as also of access to civic amenities, poverty and socio-economic deprivation.

2.3.2 *Access to Basic Services: Improved Water and Sanitation*

With the exception of Afghanistan and Bangladesh, in all the other six countries more than 90 % of its urban population had access to improved water sources in 2000. These proportions improved further in 2010. In most Countries like Maldives, Bhutan and Sri Lanka nearly had 100 % of its urban population with access to improved water. In contrast, only 36 % population in Afghanistan had access to improved water sources in 2000. But the country witnessed very rapid improvement in this area and in 2010 nearly 86 % of its urban people were covered by improved water sources. In 2010, except Afghanistan, Bangladesh and Nepal, the share of urban dwellers served by improved water was higher than South Asia average (Table 2.6). However, secondary sources showing coverage of households with water supply does not indicate the reliability of the same or assured access to the amenity. In fact, all countries in south Asia suffer from inequitable access to potable water, the problem being more serious in the slums.

The coverage with improved sanitation is far from satisfactory in most of the south Asian countries. Improved sanitation refers to facilities that include flush or pour-flush toilet to piped sewerage, septic tank or pit; a ventilated improved pit

Table 2.6 Urban population by improved water sources and sanitation

	Urban population with improved water sources (%)	Urban population with improved sanitation (%)		
Countries	2000	2010	2000	2010
Afghanistan	36	81	32	44
Bangladesh	83	85	50	54
Bhutan	99	99	66	73
India	92	96	54	59
Maldives	100	100	98	98
Nepal	94	91	42	50
Pakistan	96	96	72	72
Sri Lanka	95	98	80	82
South Asia	87	93	62	67
South and South-West Asia	92	96	62	66
World	96	96	77	79

Source: UNESCAP (2014)
Note: The figures for South Asia are the arithmetic mean of eight countries mentioned in the list
Note: The figures for South and South-west Asia include the eight counties mentioned in the list as well as Iran, Islamic Republic of and Turkey

latrine; a pit latrine with slab; or a composting toilet. In Maldives, nearly 98 % of its urban dwellers had improved sanitation in 2000 and in 2010. At the other extreme, Afghanistan has the lowest share of urban population with the same facility in both the years – 32 % and 44 % in 2000 and 2010 respectively. In 2010 countries having lower proportion of urban population served by improved sanitation as compared to South Asia average were Afghanistan, Bangladesh, India and Nepal. If we take world average into account (79 % in 2010), then all the five countries excepting Maldives and Sri Lanka rank below world average in terms of improved sanitation (Table 2.6).

2.3.3 *Poverty Ratio*

Percentage of population living below nationally defined poverty line is not represented for each of these eight countries in 2010. Among those countries, for which data is available, poverty is highest in Bangladesh and it is lowest in Sri Lanka (Table 2.7).

Unemployment Rate Which indicates the proportion of population seeking job seems to have increased in Afghanistan, Bangladesh, Bhutan and in Maldives over the last decade (2000–2010). This can partly be attributed to the fact that more of the young people are seeking work but unable to find one. However, in countries like India, Pakistan and Sri Lanka the unemployment rate did register a

Table 2.7 Population below national poverty line and unemployment rate

	Population below national poverty line (in percentage)	Unemployment rate (% of total labour force)		
Countries	2000	2010	2000	2010
Afghanistan	–	–	8.3	8.5
Bangladesh	48.9	31.5	3.3	4.5
Bhutan	–	–	1.7	3.3
India	–	29.8	4.3	3.5
Maldives	–	–	10.8	11.7
Nepal	–	25.2	2.7	2.7
Pakistan	–	–	7.2	5.1
Sri Lanka	–	8.9	7.7	4.9
South Asia	–	–	5.8	5.5
South and south-west Asia	39.0	27.8	4.8	4.5
World	–	–	6.3	6.1

Source: UNESCAP (2014)
Note: The figures for South Asia are the arithmetic mean of eight countries mentioned in the list
Note: The figures for South and South-west Asia include the eight counties mentioned in the list as well as Iran, Islamic Republic of and Turkey

decline during the same period. The decrease in unemployment rate suggests two things: either there is job generation in formal or in informal sectors where the job seekers find employment or there is a shift of young people or children from labour market to educational pursuits. Only in Nepal the unemployment rate had remained constant over time. Considering South-Asia as a unit, unemployment rate declined over time akin to the world scenario. Countries having higher unemployment rates in 2010 than South Asia average are Afghanistan and Maldives (Table 2.7).

2.3.4 Gross Domestic Product

Among the eight countries GDP growth rate is highest in Bhutan followed by India in 2010. The lowest GDP growth rate is observed in Pakistan, during the same time period. If we look at the per annum GDP growth rate over a decade i.e. from 2000 to 2010, then it is interesting to note that Afghanistan had recovered substantially from its negative GDP growth rate of 5.5 in 2000 to 3.2 % in 2010. The average GDP growth rate of South Asia is 6.6 % in 2010 and that of the world is 4 %. Countries with GDP growth rate below South Asia average in 2010 are Afghanistan, Bangladesh, Nepal and Pakistan (Table 2.8).

Per Capita GDP (2005 US$) Registered an increase across all the eight countries under consideration from 2000 to 2010. However, per capita GDP was highest in Maldives in 2010–probably because of its small population base. Not only this, in

Table 2.8 GDP growth rate, per capita GDP and GDP investment rate

	GDP growth rate (% change per annum, 2005 US$)	Per capita GDP (2005 US$)	Gross domestic investment rate (% of GDP)			
Countries	2000	2010	2000	2010	2000	2010
Afghanistan	−5.5	3.2	170	366	–	–
Bangladesh	5.9	5.8	377	583	–	–
Bhutan	8.7	11.7	992	1797	48.2	60.4
India	4.0	10.5	574	1038	24.2	37.0
Maldives	4.4	6.9	3097	5155	–	26.3
Nepal	6.1	4.8	300	384	22.5	38.3
Pakistan	4.3	1.6	641	804	15	15.8
Sri Lanka	6.0	8.0	1064	1602	25.6	27.6
South Asia	4.2	6.6	902	1466	16.9	25.7
South and South-West Asia	4.8	8.8	870	1349	23.5	31.3
World	4.2	4.0	6588	7492	23.4	23.6

Source: UNESCAP (2014)
Note: The figures for South Asia are the arithmetic mean of eight countries mentioned in the list
Note: The figures for South and South-west Asia include the eight counties mentioned in the list as well as Iran, Islamic Republic of and Turkey

Maldives, per capita GDP also registered highest increase during 2000–2010. Excepting Bhutan, Maldives and Sri Lanka, per capita GDP is lower than South Asia average in all other countries in 2010 (Table 2.8).

Gross Domestic Investment Rate The sum of gross fixed capital formation and changes in stocks divided by the total GDP in national currencies is known as Gross Domestic Investment Rate. The data for Gross Domestic Investment Rate is not available for Afghanistan and Bangladesh for both 2000 and 2010. For rest of the six countries, Gross Domestic Investment Rate had increased for Bhutan, India, Nepal, Pakistan and Sri Lanka from 2000 to 2010 (Table 2.8).

2.3.5 Value Added by Industry

According to the International Standard Industrial Classification of economic activity can broadly be classified into agricultural, industrial and service sectors. Industrial activities include construction, mining, manufacturing and utilities. Value added by Industry represents percentage of value added by these above mentioned sectors. The data suggests that with the exception of Afghanistan and Nepal, the valued added by industry has increased in all the countries in the last decade (2000–2010). This increase is most prominent in Bhutan – increased from 36 % in 2002 to 47 % in 2010 (Table2.9).

Table 2.9 Value added by industry, growth rate in value added and foreign direct investment

	Value added by industry (% of value added)	Average annual growth rate in value added by Industry (% change per annum)	FDI inward stock (% of GDP)			
Countries	2000	2010	2000	2010	2000	2010
Afghanistan	23.2	21.9	57.2	14.7	0.5	8.7
Bangladesh	23.6	26.6	8.3	11.6	4.2	5.4
Bhutan	36	44.6	18.4	20.7	1	4.2
India	26.4	27.6	10.5	18.1	3.5	12.1
Maldives	11.9	14.9	−1.5	10.9	14.5	47.7
Nepal	17.3	15.1	12.6	13.8	1.3	1.5
Pakistan	17.8	20.6	5.8	15.7	9	11.4
Sri Lanka	29.9	29.4	15.4	15	9.5	10.1
South Asia	23.3	25.1	15.8	15.1	5.4	12.6
South and South-West Asia	27.9	28.1	43.4	25	4.9	14.1
World	28.9	28.1	19.7	17.8	23.1	31.8

Source: UNESCAP (2014)
Note: The figures for South Asia are the arithmetic mean of eight countries mentioned in the list
Note: The figures for South and South-west Asia include the eight counties mentioned in the list as well as Iran, Islamic Republic of and Turkey

The average annual growth rate in value added by industry also shows an increase in 2010 as compared to the previous decade (2000). The growth rate is highest in Bhutan (20.7 %) followed by India (18.1 %) during 2000–2010. Countries like Bangladesh (11.6 %) and Maldives (10.9 %) reveals lowest growth as compared to rest of the nations during the same time period. In 2010, countries with lower growth rate in value added by industry lay than South Asia average (15.1 %) were Afghanistan, Bangladesh, Maldives and Nepal (Table 2.9).

2.3.6 *Foreign Direct Investment*

Foreign direct investment (FDI) defined FDI includes the three components of equity capital, reinvested earnings and intra-company loans. Equity capital is the foreign direct investor's purchase of shares of an enterprise in a country other than that of its residence. Reinvested earnings comprise the direct investor's share (in proportion to direct equity participation) of earnings not distributed as dividends by affiliates or earnings not remitted to the direct investor. Such retained profits by affiliates are reinvested. Intra-company loans or intra-company debt transactions refer to short – or long-term borrowing and lending of funds between direct investors (parent enterprises) and affiliate enterprises. Ownership or control of less than 10 % of a business is not considered to be FDI. Inward stock: The value of the capital and reserves in the economy attributable to a parent enterprise resident in a different economy.

This FDI inward stock is expressed as a percentage of GDP. Data shows that FDI inward stock had increased for all the eight South Asian countries from 2000 to 2010. The highest increase is observed in Maldives – from 14.5 % in 2000 to 48 % in 2010. In case of countries like India and Pakistan, the FDI inward stock nearly levels with South Asia average with marginal fluctuations. However, transactions with foreign companies seems to be limited for the small land locked nations like Bhutan and specifically with Nepal (Table 2.9).

2.3.7 *Exports of Goods and Services*

South Asia accounts for 22 % of its GDP in terms of exports of goods and services in 2012. With the exception of Afghanistan, Nepal, Pakistan and Sri Lanka, the share of exports of goods and services as a percentage of GDP has increased from 2000 to 2012. Maldives seems outstanding in this respect (Table 2.10).

Table 2.10 Exports of goods and services

Countries	Exports of goods and services (% of GDP)	
	2000	2012
Afghanistan	32	6
Bangladesh	14	20
Bhutan	29	39
India	13	24
Maldives	89	111
Nepal	23	10
Pakistan	13	12
Sri Lanka	39	23
South Asia	14	22
South and South-West Asia	30	27
World	25	30

Source: World Bank. Accessed from http://wdi.worldbank.org/table/4.8
Note: Data for South Asia was given in the website. As per World Bank, South Asian countries comprises of Afghanistan, Bangladesh, Bhutan, India, Maldives, Nepal, Pakistan and Sri Lanka

2.3.8 Emerging Interdependencies Between Urbanization and Other Economic Parameters

Using the data from the Statistical Year Book for Asia and Pacific (UNESCAP 2014), a set of indicators have been constructed. Correlation matrices have been worked out taking into account all above indicators for two time periods – 2000 and 2010 to find out how far these indicators are related to each other and how they vary over time.[5] Average annual growth rate of urban population is highly co-related with URGD in 2000 and in 2010. But the r value has slightly declined in 2010.

Importantly, the countries projected as having high URGD in the next couple of decades are those that would experience high growth in urban population as well, implying that the impact of differential demographic growth (affecting population growth in rural areas) will become less important factor in urbanization over time. The other significant point emerging from the analysis is that the countries that having a high level of urbanisation have reached a relatively high level of economic development, reflected in their high per capita income. Importantly, these would not have high rates of urban growth or URGD during the next two decades. As per the UNPD projections, the countries to record high URGD are Afghanistan, Bangladesh, Bhutan, Maldives, Nepal in South Asia and Cambodia, Indonesia, Lao PDR, Myanmar, Malaysia and Philippines, all of them (except the last two) being lowly urbanized and less developed countries. China, the largest country with relatively high level of urban industrial development, however, emerges as a major exception to this. It may nonetheless be pointed out that the present and future

[5] Since the number of observations is limited (8 in this regard), in most of the cases the results are not significant. Significance level is calculated at 0.01 and 0.05 level. The correlation matrix gives the list of indicators.

growth estimates of urban population here have considerable ambiguity and would depend on the policy perspective that the government would decide to follow.

The interdependencies of URGD and urban growth indicators for the 1990s and subsequent period with those of economic development like percentage of value added by industry and growth in this value added or total GDP turn out to be not very significant. This reconfirms the proposition that the relatively developed and urbanized countries would not be in the forefront of urbanization in future years. Further, the correlations of domestic investment, foreign investment and exports (as a proportion of GDP) with the present or future URGD turn out as negative but not statistically significant. It would nonetheless be erroneous to say that future urbanisation would be driven by poverty and push factors in less developed countries. This is because the growth in GDP and that in industrial value added relate strongly with the present URGD and urban growth and that of the coming decades. One would infer that several of the small countries that are currently at a low level of urbanization and of economic development are likely to get linked to the global capital market and report high urban growth, backed up by growth in income and industrial value added. The growth rates are likely to be high here also because of the low urban base which can be significantly impacted through a few large global projects. Understandably, the geopolitical situation in Asia would be significantly affected with this changing pattern of urban industrial investment through penetration of global agents.

Also, the share of urban population with improved water source is highly correlated with percentage of population with improved sanitation (2010); GDP growth rate (2000) and negatively related with growth rate in value added by industry (2000). The access of the people to improved water sources and sanitation facilities tend to be high in countries with high *percentage of urban population*, the corresponding correlation coefficients being statistically significant. Percentage of population with sanitation shows high correlation with per capita GDP (both in 2000 and in 2010) and with FDI inward stock (both in 2000 and in 2010). But, correlation value between improved sanitation and FDI inward stock declined in 2010 as compared to 2000. Also, GDP growth rate is significantly co-related with Gross Domestic Investment Rate and negatively with average annual growth rate in value added by industry in 2000. Also, per capita GDP is co-related with FDI inward stock in 2000. Also in 2010, FDI is highly co-related with exports of goods and services (Table 2.11 and 2.12). This indicates very strong interdependence of economic indicators among each other.

2.4 Policies and Programmatic for Interventions Affecting Migration and Urbanisation: An Overview

A review of the programmatic interventions by different countries in South Asia has been attempted in this section. Several less developed countries are attempting to build quality infrastructure in a few large cities and connect these with global

Table 2.11 Interdependencies between urbanization and other economic parameters, 2000

		Percentage of urban population 2000	Average annual growth rate of urban population, 2000	Urban rural growth differentials (2000–2005)	Percentage of urban population with improved source of water, 2000	Percentage of urban population with sanitation, 2000	GDP growth rates (% change per annum) 2005 US$	Per capita GDP (US$ 2005)	Gross domestic investment rate (percentage of GDP), 2000	Value added by industry (% of GDP), 2000	Average annual growth rate in value added by industry, 2000	FDI inward stock (% of GDP), 2000	Unemployment rate (% of total labour force), 2000	Exports of goods and services (% of GDP), 2000
Percentage of urban population 2000	Pearson correlation	1	−0.194	−0.133	0.204	0.429	0.014	0.303	−0.091	−0.112	−0.319	0.405	0.265	0.022
Average annual growth rate of urban population	Pearson correlation	−0.194	1	0.949[a]	−0.041	−0.323	0.112	−0.077	0.546	0.02	0.167	−0.533	−0.489	0.004
Urban rural growth differentials (2000–2005)	Pearson correlation	−0.133	0.949[a]	1	−0.003	−0.347	0.115	−0.074	0.335	−0.207	0.015	−0.459	−0.476	−0.03
Percentage of urban population with improved source of water	Pearson correlation	0.204	−0.041	−0.003	1	0.672	0.915[a]	0.445	0.662	−0.013	−0.915[a]	0.464	−0.217	0.135
Percentage of urban population with sanitation	Pearson correlation	0.429	−0.323	−0.347	0.672	1	0.462	0.864[a]	0.069	−0.174	−0.659	0.893[a]	0.499	0.665
GDP growth rates (% change per annum)	Pearson correlation	0.014	0.112	0.115	0.915[a]	0.462	1	0.225	0.886[b]	0.247	−0.787[b]	0.187	−0.508	−0.047
Per capita GDP (US$ 2005)	Pearson correlation	0.303	−0.077	−0.074	0.445	0.864[a]	0.225	1	0.543	−0.374	−0.494	0.801[b]	0.587	0.917[a]

(continued)

Table 2.11 (continued)

		Percentage of urban population 2000	Average annual growth rate of urban population, 2000	Urban rural growth differentials (2000–2005)	Percentage of urban population with improved source of water, 2000	Percentage of urban population with sanitation, 2000	GDP growth rates (% change per annum) 2005 US$	Per capita GDP (US$ 2005)	Gross domestic investment rate (percentage of GDP), 2000	Value added by industry (% of GDP), 2000	Average annual growth rate in value added by industry, 2000	FDI inward stock (% of GDP), 2000	Unemployment rate (% of total labour force), 2000	Exports of goods and services (% of GDP), 2000
Gross Domestic investment rate (percentage of GDP)	Pearson correlation	−0.091	0.546	0.335	0.662	0.069	0.886[b]	0.543	1	0.858	0.862	−0.574	−0.659	0.456
Value added by industry (% of GDP)	Pearson correlation	−0.112	0.02	−0.207	−0.013	−0.174	0.247	−0.374	0.858	1	0.293	−0.494	−0.532	−0.406
Average anuual growth rate in value added by industry	Pearson correlation	−0.319	0.167	0.015	−0.915[a]	−0.659	−0.787[b]	−0.494	0.862	0.293	1	−0.601	0.071	−0.173
FDI inward stock (% of GDP)	Pearson correlation	0.405	−0.533	−0.459	0.464	0.893[a]	0.187	0.801[b]	−0.574	−0.494	−0.601	1	0.732[b]	0.661
Unemployment rate (% of total labour force)	Pearson correlation	0.265	−0.489	−0.476	−0.217	0.499	−0.508	0.587	−0.659	−0.532	0.071	0.732[b]	1	0.683
Exports of goods and services (% of GDP)	Pearson correlation	0.022	0.004	−0.03	0.135	0.665	−0.047	0.917[a]	0.456	−0.406	−0.173	0.661	0.683	1

Source: UNESCAP (2014) and World Urbanisation Prospects: The 2014 Revision
[a]Correlation is significant at the 0.01 level (2-tailed).
[b]Correlation is significant at the 0.05 level (2-tailed)

Table 2.12 Interdependencies between urbanization and economic indicators, 2010

		Percentage of urban population, 2010	Average annual growth rate of urban population, 2010	URGD (2005–2010)	Percentage of urban population with improved source of water, 2010	Percentage of urban population with sanitation, 2010	GDP growth rates (% change per annum), US$ 2005	Per capita GDP (US$ 2005)	Gross domestic investment rate (% of GDP), 2010	Value added by industry (% of GDP), 2010	Average annual growth rate in value added by industry, 2010	FDI inward stock (% of GDP), 2010	Unemployment rate (% of total labour force), 2010	Exports of goods and services (% of GDP), 2012
Percentage of urban population, 2010	Pearson correlation	1	0.577	0.516	0.366	0.49	0.111	0.554	−0.066	0.112	0.052	0.572	0.413	0.596
Average annual growth rate of urban population	Pearson correlation	0.577	1	0.845[a]	−0.187	0.017	−0.106	0.4	0.26	−0.165	−0.224	0.419	0.524	0.499
Urban rural growth differentials (2005–2010)	Pearson correlation	0.516	0.845[a]	1	0.248	0.313	0.215	0.584	0.448	0.016	−0.062	0.429	0.318	0.662
Percentage of urban population with improved source of water	Pearson correlation	0.366	−0.187	0.248	1	0.831[b]	0.518	0.618	0.054	0.23	0.319	0.426	−0.016	0.554
Percentage of urban population with sanitation	Pearson correlation	0.49	0.017	0.313	0.831[b]	1	0.282	0.866[a]	−0.289	0.039	−0.104	0.738[b]	0.453	0.797[b]
GDP growth rates (% change per annum)	Pearson correlation	0.111	−0.106	0.215	0.518	0.282	1	0.288	0.77	0.7	0.544	0.02	−0.275	0.307
Per capita GDP (US$ 2005)	Pearson correlation	0.554	0.4	0.584	0.618	0.866[a]	0.288	1	−0.114	−0.148	−0.292	0.925[a]	0.702	0.987[a]
Gross domestic investment rate (% of GDP)	Pearson correlation	−0.066	0.26	0.448	0.054	−0.289	0.77	−0.114	1	0.718	0.667	−0.396	−0.445	−0.044

(continued)

Table 2.12 (continued)

		Percentage of urban population, 2010	Average annual growth rate of urban population, 2010	URGD (2005–2010)	Percentage of urban population with improved source of water, 2010	Percentage of urban population with sanitation, 2010	GDP growth rates (% change per annum), US$ 2005	Per capita GDP (US$ 2005)	Gross domestic investment rate (% of GDP), 2010	Value added by industry (% of GDP), 2010	Average annual growth rate in value addded by industry, 2010	FDI inward stock (% of GDP), 2010	Unemployment rate (% of total labour force), 2010	Exports of goods and services (% of GDP), 2012
Value added by industry (% of GDP)	Pearson correlation	0.112	−0.165	0.016	0.23	0.039	0.7	−0.148	0.718	1	0.767[b]	−0.424	−0.463	−0.155
Average annual growth rate in value added by industry	Pearson correlation	0.052	−0.224	−0.062	0.319	−0.104	0.544	−0.292	0.667	0.767[b]	1	−0.471	−0.56	−0.322
FDI inward stock (% of GDP)	Pearson correlation	0.572	0.419	0.429	0.426	0.738[b]	0.02	0.925[a]	−0.396	−0.424	−0.471	1	0.846[a]	0.916[a]
Unemployment rate (% of total labour force)	Pearson correlation	0.413	0.524	0.318	−0.016	0.453	−0.275	0.702	−0.445	−0.463	−0.56	0.846[a]	1	0.684
Exports of goods and services (% of GDP)	Pearson correlation	0.596	0.499	0.662	0.554	0.797[b]	0.307	0.987[a]	−0.044	−0.155	−0.322	0.916[a]	0.684	1

Source: UNESCAP (2014) and World Urbanisation Prospects: The 2014 Revision
[a]Correlation is significant at the 0.01 level (2-tailed)
[b]Correlation is significant at the 0.05 level (2-tailed)

markets for attract international capital. The objective is also to maximise macro-economic growth in the country by reaping economies of production in these agglomerations. Despite the governments putting forward a positive and liberal perspective on urbanization and migration, they have gone for 'sanitisation drives' pushing out "low valued" activities including slum colonies from the city core to the peripheries, to create space for these companies and their executive staff. The fiscal regime brought about through newly created regulatory authorities and credit rating agencies have encouraged these cities, with strong economic base and high capacity for generating tax and non-tax revenue, mobilise enormous resources from institutional sources, using innovative financial instruments. The decentralisation of planning responsibilities resulting in privatisation of many civic services and withdrawal of public subsidies, thereby pushing up their prices. All these are having a dampening effect on migration into these cities (Kundu and Kundu 2010).

In South East Asia too governments have launched city level initiatives making it difficult for the migrants to become legal residents of the city. For example, in Indonesia,[6] cleaning up the city of Jakarta and reducing its population growth has been taken up as a national goal and the government is desperately trying to promote reverse migration.

An important component of the strategy to promote the global cities with high quality infrastructure is to contain their demographic growth through *development of satellite towns*. Webster (2004) underlines the importance of peripheral development around metro cities in understanding urbanization in less developed countries. He argues that peri-urban areas have experienced rapid economic growth as these can more easily absorb the migrants and provide space for new manufacturing structures. In addition, "large segments of the existing poor, living in urban cores are being pushed to the periphery by land market forces or drawn there by employment opportunities". Importantly, their informal activities along with other pollutant industries are also being shifted out to the 'degenerated periphery'. All these measures have most certainly decelerated the demographic growth in metropolitan cities and also brought down the overall rate of urbanisation in many of these countries (Kundu and Kundu 2010).

As per a study by United Nations (2000), 44 % of the countries of the world, of which 88 % are in less developed regions, consider their settlement pattern to be a matter of major national concern. Faced with the problems of metropolis based growth, these countries have tried to disseminate infrastructure and basic facilities in rural areas and promote development there. Understandably, settlement policies have become synonymous with measures to reduce or reverse RU migration through balanced regional development.

[6] Indonesian government had declared Jakarta a special metropolitan district in 1966, which had attracted huge inflow of population, resulting in Jakarta urban agglomeration growing into the adjacent province of West Java, known as Jabotabek. The population of Jabotabek region was about 25 million in 2000 despite the government adopted strong measures to control growth of population launched in early 1970s by prohibiting the entry of unemployed migrants.

India, while not implementing direct controls on population movement, has a range of policies for rural development which is expected to slow down migration. National Rural Employment Guarantee Programme, which promises 100 days of wage labour to one adult in every rural household in unskilled work is a major new initiative at the country level, expected to check out-migration (Kundu and Kundu 2010). Similar policies and institutional actions have been proposed by the Government of the People's Republic of Bangladesh (2003) in its 'National Strategy for Economic Growth, Poverty Reduction and Social Development'. It delineates programmes to reach out to poor and remote rural areas that are vulnerable to adverse ecological processes, particularly through micro-credit programmes as promoted through Grameen Bank. Most of the less developed countries in Asia can thus be seen as trying to channel private investments to designated areas and removing subsidies that previously favoured locations like the mega cities or the national capital. The idea behind this approach is to create "level playing field" in backward regions whereby at least certain locations in their countryside become attractive for investors and migrants.

Many governments in Asia have launched programmes at state and local levels to improve the micro environment in slums and squatter settlements. Civil society orgnisations and human right activities too have occasionally succeeded in forcing the government to provide basic amenities in these settlements through the intervention of Court. Unfortunately, however, resource availability for such programmes and their spatial coverage have gone down in recent years, under new systems of governance, reducing subsidies in social sectors. Withdrawal of the State and Local governments and their becoming increasingly dependent on capital market have also affected their capacity to extend services to the poor. Economic downturn of 1990s and the more recent one during 2008–2009 have weakened their commitment to these policies. Often the central government support has become contingent on the regional and local government's accepting measures for reforming land and capital markets and creating enabling conditions for private investment in city infrastructure and basic services. Concerns for affordability, cost recovery and participation of resident associations in better-off areas have been responsible for ushering in a process of elite capture. This has enabled the upper and middle income households corner a large chunk of resources, made available by national and international agencies, meant for the poor.

There has been avowed concern for socioeconomic upliftment of the workers in unorganised sector absorbing the migrants in most countries, and yet nothing concrete has come up in term of programmatic interventions. The lukewarm response of the private sector to provisioning civic amenities, too, has contributed to dilution of pro-poor and pro-migrant thrust in policies. Civil society organisations have become active in stopping illegal encroachment of public spaces, including parks, pavements etc., through public interest litigations and the judiciary is increasingly upholding the rights of the 'formal citizens'. All these, have led to poor migrants being pushed into either marginal lands within the city or in degenerated peripheries, resulting in increasing disparity in the quality of micro environments, segmentation of urban space and reduction of land for poor migrants (Kundu and Kundu 2010).

2.5 A Summary of Findings

One can put forward the thesis of exclusionary urban growth in most South Asian countries which is linked with formal or informal denial of entry to the prospective migrants and increased unaffordability of urban space and basic amenities by the rural poor based on an overview of the macro statistics. The projections of urban population made by United Nations Population Division and accepted by other international organizations, national governments and most researchers have generally turned out to be on higher side in case of several countries in South Asia. This is largely due to the methodology adopted by UNPD based on an exponential model.

The spatial scenario of urban growth as projected by UNPD suggests that small and less developed countries in south Asia may record high population growth in their urban centres, but the growth rates have been projected to slow down during the next few decades. These have shown high pace of urbanization and rapid economic growth in recent years, backed up by foreign and domestic investment. Moreover, the structure of urban growth has been top heavy for most of the south Asian countries where a few large cities (million plus) account for a high proportion of urban population. Due to their low economic base, a few big projects from national or global corporate agency can push up the growth rate of urban population. Urbanisation pattern in South Asia would therefore get diversified, shifting away from more developed countries, which is likely to have an impact on the geo-political balance in the continent. The model of exclusionary urbanization, however, suggests that the percentage of urban population and urban growth rates in these countries may be significantly below the projected figures. This is corroborated by the fact that the employment elasticity of fast growing global sectors is low and the governments are trying to create quality cities through massive infrastructural investment and cleaning of slums. It is possible that many of the governments would shift the thrust of development to small and medium towns that unfortunately have reported economic stagnation in recent years. This change could become a political compulsion due to the tensions linked to accentuation of regional inequality and rural poverty acquiring serious proportions. This would imply a paradigm shift in the settlement policy in these countries.

An overview of the pattern of interdependencies among select development indicators suggests that the *level* of urbanization relates strongly and positively with that of economic development, and also with domestic/foreign investment, export base etc. The latter, however, do not have much impact on growth of urban population and URGD. This suggests that a high rate of economic growth in a country does not necessarily bring in labour force into urban centres. The high rates of domestic and foreign investment do not seem to promote urbanization through immigration of poor and unemployed labourforce as the former do not exhibit positive or negative correlation with the rate of poverty or unemployment. This could possibly be due to high skill requirement and low labour intensity in global sectors. These would strengthen the process of elite capture in the global cities which has ushered in a process of "sanitization" and cleaning up the micro environment by pushing out the current and prospective migrants out of the city boundaries. The exclusionary nature of urban growth is manifest in policies and programmes adopted by the state and city governments to discourage entry of poor and unskilled migrants from rural areas as also from outside the country, especially those coming with their dependents. Given the political economy of urban growth and need to attract global and domestic capital into these cities, the government may not interfere with "elitist interest" and continue to adopt a restrictive attitude towards poor RU migrants. There exists no definitive evidence suggesting that urban growth has resulted in increased access of people to basic amenities like drinking water and sanitation to the average people. All these would dampen the pace of urban growth notwithstanding the magnitude of absolute figures of increment that are large due to the pure demographic weight of the region. South Asia is unlikely to go the same way as that of Latin America in the second half of the last century.

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Part II
India

Chapter 3
Prioritizing Watersheds for Sustainable Development in Swan Catchment Area, Himachal Pradesh, India

Amit Kumar Batar, R.B. Singh, and Ajay Kumar

Abstract Land and Water resources form the base for development and utilization of other resources. The depletion and degradation of these resources has happened at a very fast pace in developing countries like India. Many resource development programmes have been undertaken in India to tackle the problem of land and water resources and have been applied generally on watershed basis. Thus, prioritization is essential for proper planning and management of natural resources for sustainable development. Mountain watersheds have attracted global concern due to the threat of serious environmental and socio-economic implications arising from natural resource degradation. Increasing recreational pressures within the mountains, demand for hydro-power, and increasing climatic variability are major concerns of present time Himalayas. Therefore, the basic objective of the prioritization of watersheds is proper management in the most vulnerable parts of the watershed so as to minimize the siltation rate in the active stream or reservoirs. The study area of Swan catchment falls under Una district. The river Swan has a total catchment of 140,000 ha out of which 120,000 (85.7 %) ha lies in the Himachal Pradesh. The river is fed by about 82 tributaries during its traverse in Himachal Pradesh. In district Una, river Swan flows through inter-mountainous valley. The study has used both primary and secondary databases. In the present study, the parameters considered for prioritization of watershed were from the natural resources thematic map data, including soil, drainage density, surface water prospects, groundwater prospects, irrigated area, forest cover and Land use land cover derived from satellite imagery and socio-economic data. In the present study, weightage system has been adopted for sub-watershed prioritization based on its factors and after carefully observing the field situation. The basis for assigning weightage to different themes was according to the relative importance to each

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parameter in the study area. The weightage system adopted here is completely dependent on local terrain and may vary from place to place. The prioritization results of study shows that 4 sub-watersheds SWL36, SWL6, SWR54, and SWR69 need very high priority, 29 sub-watersheds need high priority, 16 sub-watersheds fall in medium priority and 32 sub-watersheds fall in very low and Low priority.

Keywords Watershed • Land resources • Soil erosion • Socio-economic condition • Himalayas • Swan catchment

3.1 Introduction

Land and Water resources are limited and their extensive utilization is necessary, especially for populated countries like India. Thus prioritization is essential for proper planning and management of natural resources for sustainable development (Vittala et al. 2008). Drainage basins, catchments and sub-catchments are the fundamental units of the management of land and water, identified as planning units for administrative purposes to conserve natural resources (Moore and Burch 1977). Mountain watersheds have attracted global concern due to the threat of serious environmental and socio-economic implications arising from natural resource degradation (Liniger et al. 1998; Gleick 2002; Smil 2001; Schindler 2001). Today, degraded watersheds in mountain areas are among the greatest constraints to sustainable development in the developing world. The need for the careful management and sustainable use of watersheds has never been greater. The sustainability in watershed management can be achieved through participatory process that involves people and aims to improve their livelihoods (Swami and Kulkarni 2011). The Shivaliks lie in the foothills of the Himalayan range. This region has been identified as one of the most degraded rainfed areas of the country and has been included as priorities in watershed development. Acute shortages of drinking water, fodder, and fuel-wood exist due to deforestation, and land degradation. Subsistence rainfed agriculture is the prevalent production system in the Shivaliks. The Shivaliks are facing serious problems like soil erosion, degradation of water catchment areas which is reducing agricultural productivity (Mittal and Aggarwal 2002). River Swan in the Shivaliksis considered as "Sorrow" for the region during the monsoon season. The famous heavy flood damages of 1988 are still fresh in the mind of the people (SRIWMP 2014). Approximately 10,000 ha. of agricultural land is affected by floods, and annually 2000 ha. of fertile land is not being cultivated due to fear of floods. The Swan river catchment is characterized by fragile and vulnerable Shivalik hills and sparse vegetative cover. According to the analysis of Agriculture Department, 75 % of Una district falls under the category of severe erosion prone area, whereas 33 % of the whole state is categorized into severe erosion prone area (SRIWMP 2014). Watershed prioritization is one of the most important aspects of planning for implementation of its development and management programmes. Therefore, the paper aims to identify priority watersheds in Swan catchment for sustainable planning based on morphometric, socio-economic and physical characteristics of the watersheds.

3.2 Study Area

The Swan catchment falls under Una district. The river Swan originates from Joh-Marwari village near Daulatpur Chowk in Amb tehsil in district Una, Himachal Pradesh. The Swan River traverses a total distance of 65 km in Himachal Pradesh. The river Swan has a total catchment of 140,000 ha out of which 120,000 (85.7 %) ha lies in the Himachal Pradesh. The river is fed by about 82 tributaries during its traverse in Himachal Pradesh. The catchment lies between North latitude 31°18′ and 31°55′ and East longitude 75°55′ and 76°28′ (Fig. 3.1). Administratively, the region has been divided into two sub-divisions (Una and Amb) and comprises of four tehsils (Una, Amb, Bangana, Haroli) and one sub-tehsil (Bharwain). Further, there are five CD blocks (Una, Amb, Gagret, Dhundla (Bangana) and Haroli). There are five towns (Una, Mehtpur Badshera, Gagret, Santhokhgarh and Daulatpur), 758 inhabited villages, 56 uninhabited and 235 g Panchayats in the district. The catchment can be divided into two main physiographic regions that is (i) Rainfed Hilly Tract with elevation between 450 and 900 m or above and (ii) Irrigated Plain Valley Tract with elevation between 350 and 450 m from the MSL (Fig. 3.2). The elevations of the region vary from 340 m in south-eastern part to 1041 m above sea level (ASL) in eastern part of the district. The vast area between the northwesterly and southeasterly hill ranges, on both sides of river Swan or Soan is the Una valley. The undulating plain fertile Una valley has an area of about 455 sq km and it extends from Daulatpur in the North West to Santokhgarh in the south east. The mean minimum temperature various between 4 °C to 6 °C in January and mean maximum around 36 °C in June in Una. But the minimum temperature in the district can drop to freezing point during January and can go upto 44 °C in the month of May-June. District Una receives a good quantum of precipitate of around 1231 mm per annum.

3.3 Research Methodology

3.3.1 Database

The study has used both primary and secondary databases. The primary information has been collected with the help of questionnaire survey. A semi structured questionnaire has been used for this purpose. The selection of interviewees has been done through stratified random sampling method. The study area is divided into regions on the basis of agro-ecological situations and about 25 households from agro-ecological situations, thereby making a total of approximately 100 households. In the present study, the parameters considered for prioritization of watershed were from the natural resources thematic map data, including soil, drainage density, surface water prospects, groundwater prospects, irrigated area, forest cover and Land use land cover derived from satellite imagery and socio-economic data (sex

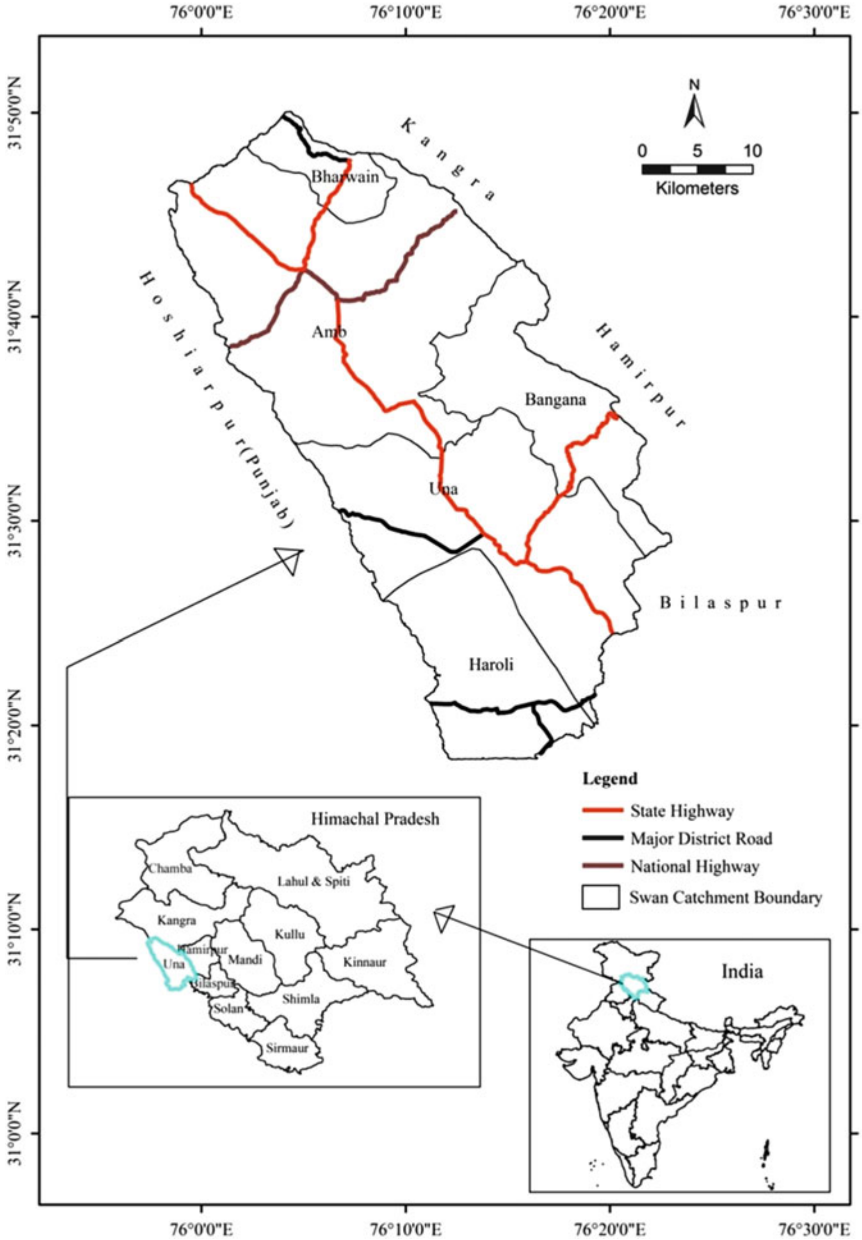

Fig. 3.1 Location of the Swan Catchment, Himachal Pradesh (Source: Central Ground Water Board, 2007)

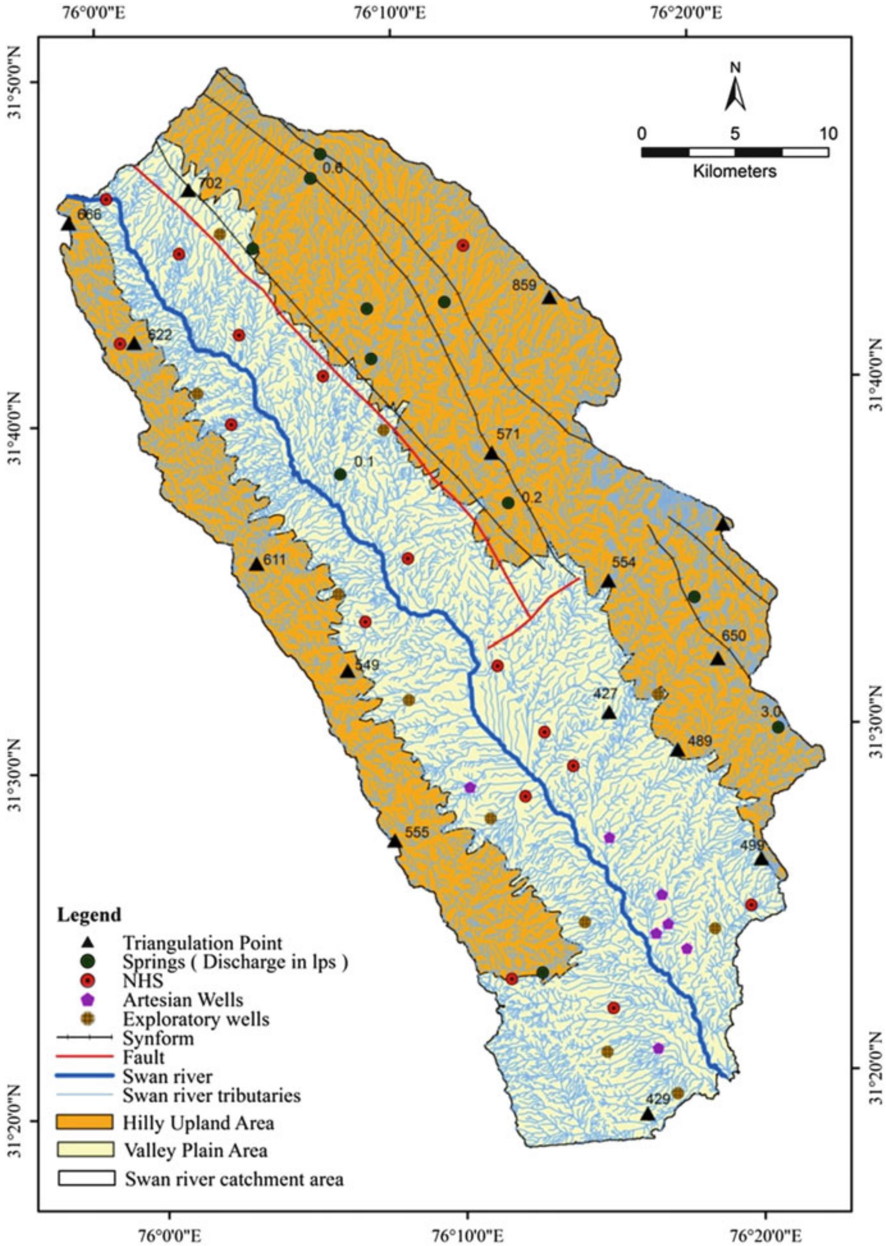

Fig. 3.2 Hydrogeology of the Swan Catchment, Himachal Pradesh

ratio, education facility, land availability, forest availability, power supply facility, health facility, bank facility, livestock availability, expenditure, road accessibility, migration status, transport facility, distance of nearest town, population of agricultural labourers and female working population). The slope map was prepared from DEM Cartosat 1.1r of ISRO, Bhuvan satellite having contour interval available at 20 m. The socio-economic details pertaining to prioritization watershed were drawn from Census of India 2001, Primary census abstract (2001–2011) and agriculture department of Una, Una district, Himachal Pradesh. The station-wise average annual rainfall data for 7 years has been collected from department of agriculture, Una district. The land use/cover data has been extracted from satellite images acquired by Indian Remote Sensing Satellites available with National Remote Sensing Agency (NRSA), Hyderabad available at BHUVAN open Data Portal. The Cartosat image has also been acquired from BHUVAN, along with the month wise NDVI, Water Index and Albedo images. Data on food production growth rate has been taken from District Agriculture Statistics Handbook. Information about ground water position has been sourced from Ground Water Commission. Data related to Expenditure, per capita income and income source has been taken from website of Government of Himachal Pradesh. Information regarding livestock is collected from Livestock Census of Himachal Pradesh. Water discharge data of swan river and tributaries data collected from the Swan river flood management project Una district, Himachal Pradesh, and other relevance report as agriculture, aquifer system, ground water, socio-economic status from Department of, agriculture, irrigation cum public health, Centre for Geo-informatics Research and Training (CSK, Palampur) Agricultural Technology Management Agency, Indian Metrological Department (IMD) Statistical Abstract, Fisheries, Agricultural Technology Management Agency (ATMA), Ministry of Micro, Small and Medium Enterprice Mines (MSME) and Geology, Government of Himachal Pradesh respectively, were also considered for prioritization of sub-watersheds.

3.3.2 Data Analysis

Erdas Imagine was mainly used for image processing purpose. ArcGIS10 software was used for digitizing morphometric analysis, assessments of physical environment, assessments of socio-economic status and to generate output. For mapping of watersheds and their boundaries, information on height provided through contours and spot heights given in DEM 1.1 r were used in Arc GIS through SWAT model. The methods adopted for calculating morphometric parameters have been carried out of the following parameters: bifurcation ratio (Rb), (Linear parameters), basin relief (Bh), relief ratio (Rh) and ruggedness number (Rn) (Relief parameters) and drainage density (Dd), stream frequency (Fs), texture ratio (T), form factor (Rf), length of overland flow (Lof), constant channel maintenance (C) (Aerial parameters) (Biswas et al. 1999) (Table 3.1).

The universal soil loss equation was used to determine the average annual soil loss and its spatial distribution on the watershed (Jain et al. 2001). The Universal soil loss equation (USLE) predicts soil loss for a given site as a product of six major

Table 3.1 Priority of morphometric parameters

Parameter	Priority
Bifurcation ratio (R_b)	High value more priority
Drainage density (D_d)	High value more priority
Stream frequency (F_s)	High value more priority
Elongation ratio (Re)	High value more priority
Texture ratio (T)	Less value more priority
Form factor (R_f)	Less value more priority
Circulatory ratio (R_c)	Less value more priority
Compactness coefficient (c_c)	Less value more priority

Source: Compiled by researcher

erosion factors, whose values at a particular location can be expressed numerically. USLE is suitable for predicting long-term averages and the soil erosion is estimated as follows:

$$A = R \times K \times L \times S \times C \times P$$

Where; A is average annual soil loss rate (t/ha/year), R is rainfall erosivity factor (MJ-mm/ha/h/year), K is soil erodibility factor (t-ha-h/ha/MJ/mm), LS is topographic factor, C is crop management factor and P is conservation supporting practice factor.

The assessment of physical environment conditions includes land use land cover, soil quality, climate condition, water quality, and slope. Assessment of water quality includes water quality parameters like pH, Temperature, Dissolved Oxygen (DO), Biochemical Oxygen Demand (BOD), Nitrate (NO_3), Sulphate (SO_4) Hardness, Chloride (C_l), Total Phosphorous, Total Dissolved Solids (TDS), Turbidity, Total coli form, and Fluoride (F) in up and down stream of swan catchment area. For socio-economic prioritization of sub-watersheds, Agricultural Land Availability, Forest Availability, Education Facility, Credit Facility/Banking, Road Accessibility, Irrigation Facility and Agriculture productivity, are used as indicators (Table 3.2).

In the present study, weightage system has been adopted for sub-watershed prioritization based on its factors and after carefully observing the field situation. The basis for assigning weightage to different themes was according to the relative importance to each parameter in the study area. The weightage system adopted here is completely dependent on local terrain and may vary from place to place (Fig. 3.3).

Table 3.2 Methods of calculating socio-economic indicators

Parameter	Priority
Agricultural land availability	Less value more priority
Forest availability	Less value more priority
SC/ST population (in percentage)	More value more priority
Education facility	Less value more priority
Credit facility/banking	Less value more priority
Road accessibility	Less value more priority
Irrigation facility	Less value more priority
Agriculture productivity	Less value more priority

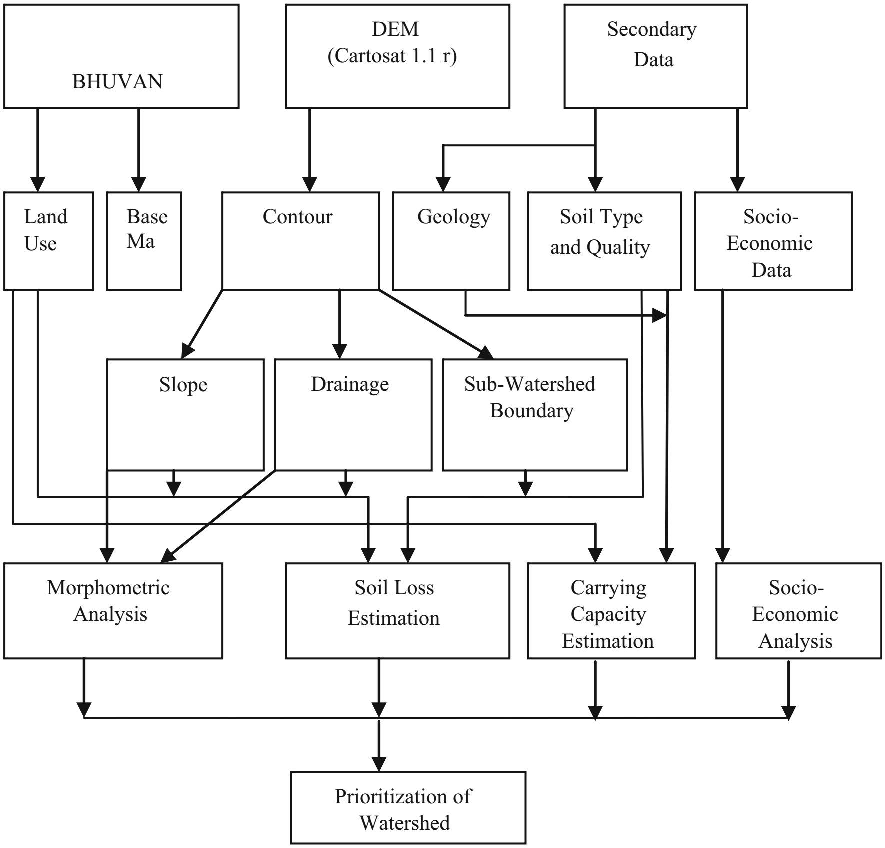

Fig. 3.3 A methodological framework for prioritizing watershed for sustainable development

3.4 Results and Discussion

3.4.1 Prioritization Based on Morphometric Parameters

The morphometric prioritization result shows that only 10 sub-watershed falls under very high priority, 24 sub-watersheds all under high priority, 24 - sub-watershed falls under moderate priority, 18 sub-watershed falls under low priority, 6 sub-watershed falls under very low priority (Fig. 3.4).

3.4.2 Soil Loss for Prioritization

The soil loss prioritization results shows that only 9 sub-watershed falls under very high priority, 8 sub-watersheds falls under high priority, 11 sub-watershed falls under moderate priority, 17 sub-watershed falls under low priority, 37 - sub-watershed falls under very low priority (Fig. 3.5).

3.4.3 Carrying Capacity Estimation for Prioritization

Carrying capacity is defined as the environment's maximal load, or the maximum number of individuals of a given species that an area's resources can sustain indefinitely without significantly depleting or degrading those resources. Carrying capacity can be concerned with population growth of humans and other species of living organisms (Paehlke 1995). In the ecological sense, carrying capacity is related to the "study of population dynamics" (Paehlke 1995). When a species grows rapidly over the carrying capacity of its environment (i.e. overpopulation) it results in problems (Dashefsky 1993). When the species crowds its environment (i.e. ecosystem, habitat, etc.) resulting in diminished resources, its "growth will decline" (Paehlke 1995). When this occurs the population of the species will "level off and eventually cease to grow or even suffer from a severe decline" (Paehlke 1995).

In the present study, carrying capacity is based on land use and land capability assessment and estimation of land potential of the Swan catchment (Fig. 3.6). The calculations on soil quality and land use/land cover availability to determine the land sustainability so that land resources are used within their capability. The Carrying capacity prioritization results that only 16 sub-watershed falls under very high priority, 18 sub-watersheds falls under high priority, 18 sub-watershed falls under moderate priority, 21 sub-watershed falls under low priority, 9 - sub-watershed falls under very low priority (Fig. 3.7).

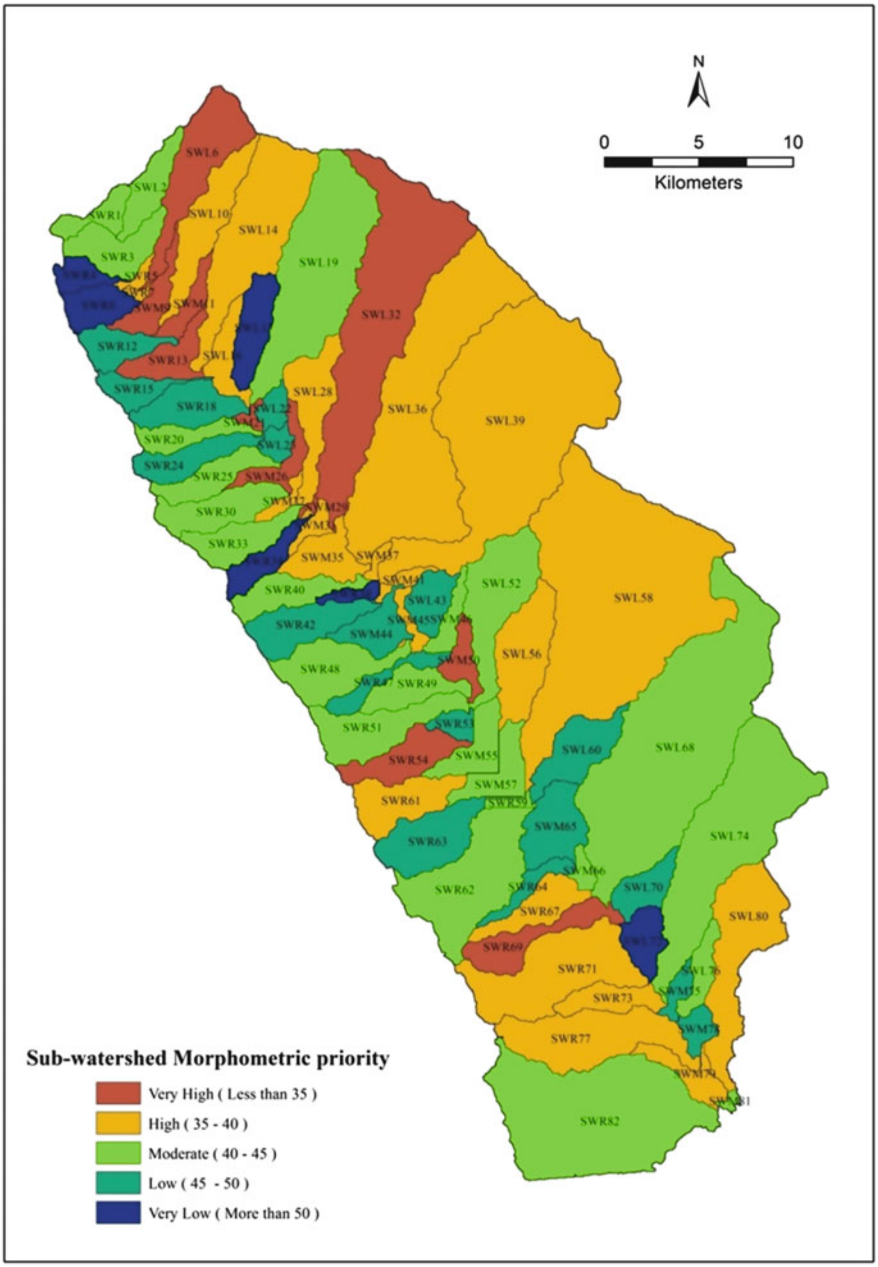

Fig. 3.4 Compound morphometric value of the sub-watersheds

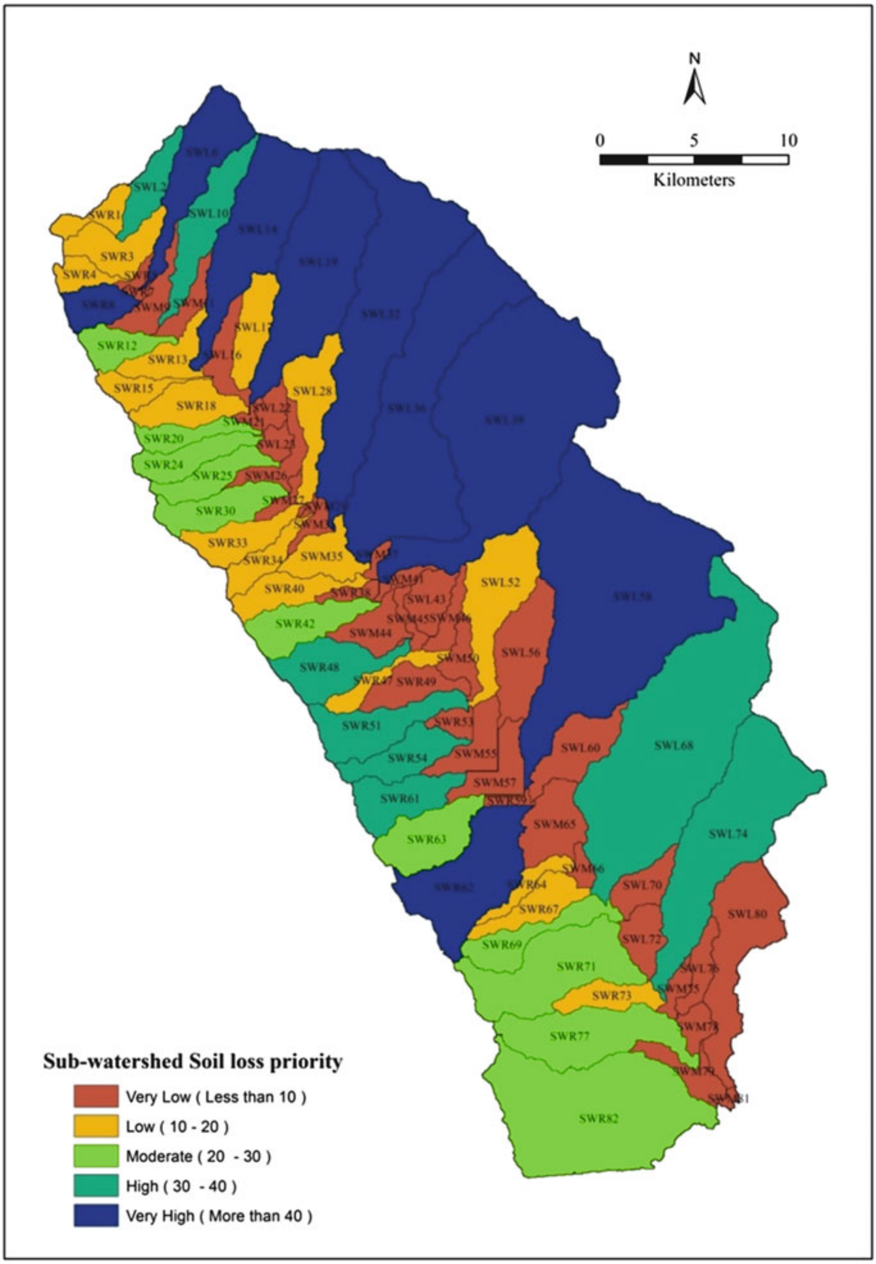

Fig. 3.5 Compound soil loss values of the sub-watersheds in the Swan Catchment

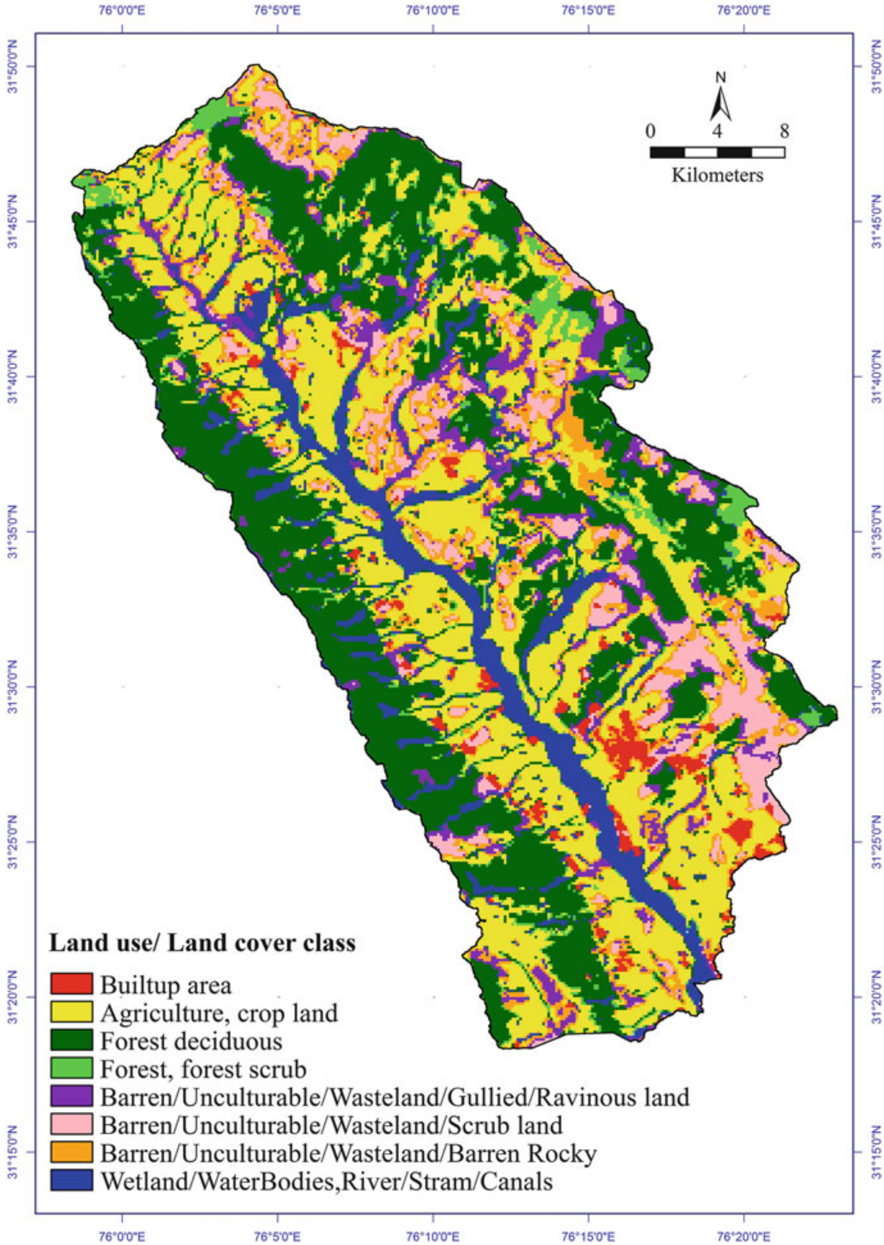

Fig. 3.6 Land use/land cover of the Swan Catchment, 2012

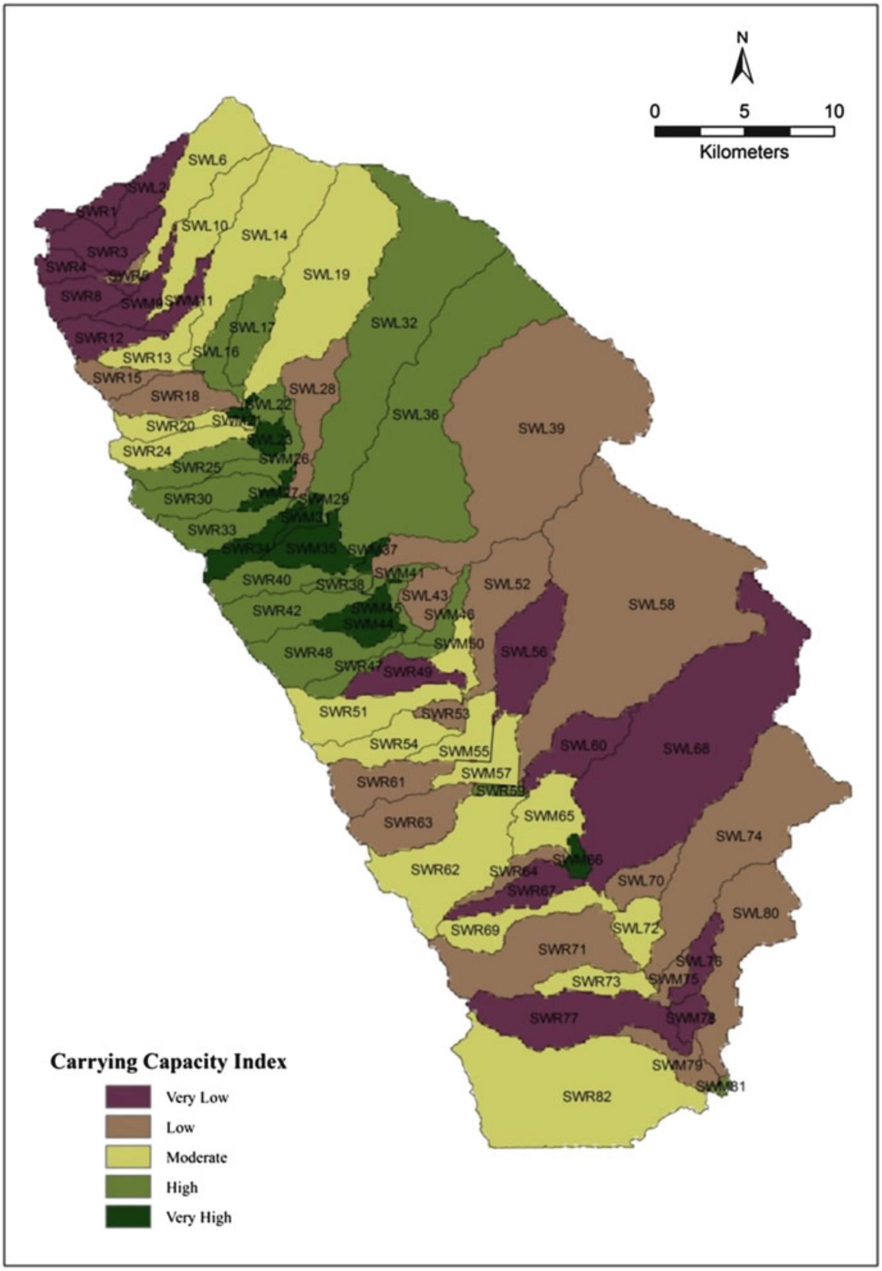

Fig. 3.7 Carrying capacity of land based on soil fertility

3.4.4 Socio-economic Indicators for Prioritizing

After the rating has been assigned to all the socio-economic indicators based on every single indicator, the rating value for all the 82 sub-watersheds were averaged so as to arrive at a compound value (Cp). This compound value of the sub-watersheds was used to prioritize. This Compound value of the sub-watersheds was used to prioritize on the basis of their socio-economic indicators, hence the sub-watershed which has lowest Cp value has been given priority one, next lowest value has been given second priority and so on.

The socio-economic prioritization results shows that only 11 sub-watershed falls under very high priority, 27 sub-watersheds all under high priority, 27 -sub-watershed falls under moderate priority, 15 sub-watershed falls under low priority, 2 sub-watershed falls under very low priority (Fig. 3.8).

3.4.5 Prioritization of Sub-watershed

For prioritization of sub-watersheds, based on Morphometric, Soil loss, Socio-economic analysis the lowest value was given rating of 1; next higher value was given a rating of 2 and so on. The compound parameter values of all 82 -Sub-watersheds of the Swan catchment area are calculated and prioritization rating.

The sub-watersheds have been broadly classified into five priority zones according to their compound value (Cp); very high (Less than 20) high (20–35), moderate (35–45), low (45–60) and very low (More than 60) (Fig. 3.9).

Very High and High Priority There are 4 sub-watersheds falling in very high priority. The sub-watersheds which fall in Very high priority category are SWL36, SWL6, SWR54, and SWR69. These watersheds generally consist of steep slopes, high drainage density, high stream frequency, low form factor and low elongation ratio. These can be classified under very severe erosion susceptibility zone. Thus need immediate attention to take up mechanical soil conservation measures gully control structures and grass waterways to protect the topsoil loss.

Medium Priority There are 16 sub-watersheds falling in medium priority. These include SWR3, SWM9, SWM11, SWR12, SWR15, SWL16, SWR18, SWR25, SWM27, SWL28, SWR30, SWR34, SWM45, SWR 47, SWR48, SWR63, SWL76. These watersheds consist of moderate slopes, moderate values of drainage density, stream frequency, drainage texture and moderate to high form factor, circulatory ratio and elongation ratio.

Very Low and Low Priority There are 32 sub-watersheds falling in very low and Low priority. This category has been attained by SWR4, SWR8, SWL17, SWM21, SWL22, SWR24, SWM29, SWM31, SWM35, SWM37, SWR38, SWL43, SWM44, SWM46, SWR49, SWM50, SWL52, SWM55, SWL56, SWM57, SWR59, SWL60, SWR64, SWM65, SWM66, SWL70, SWL72, SWM75, SWL76

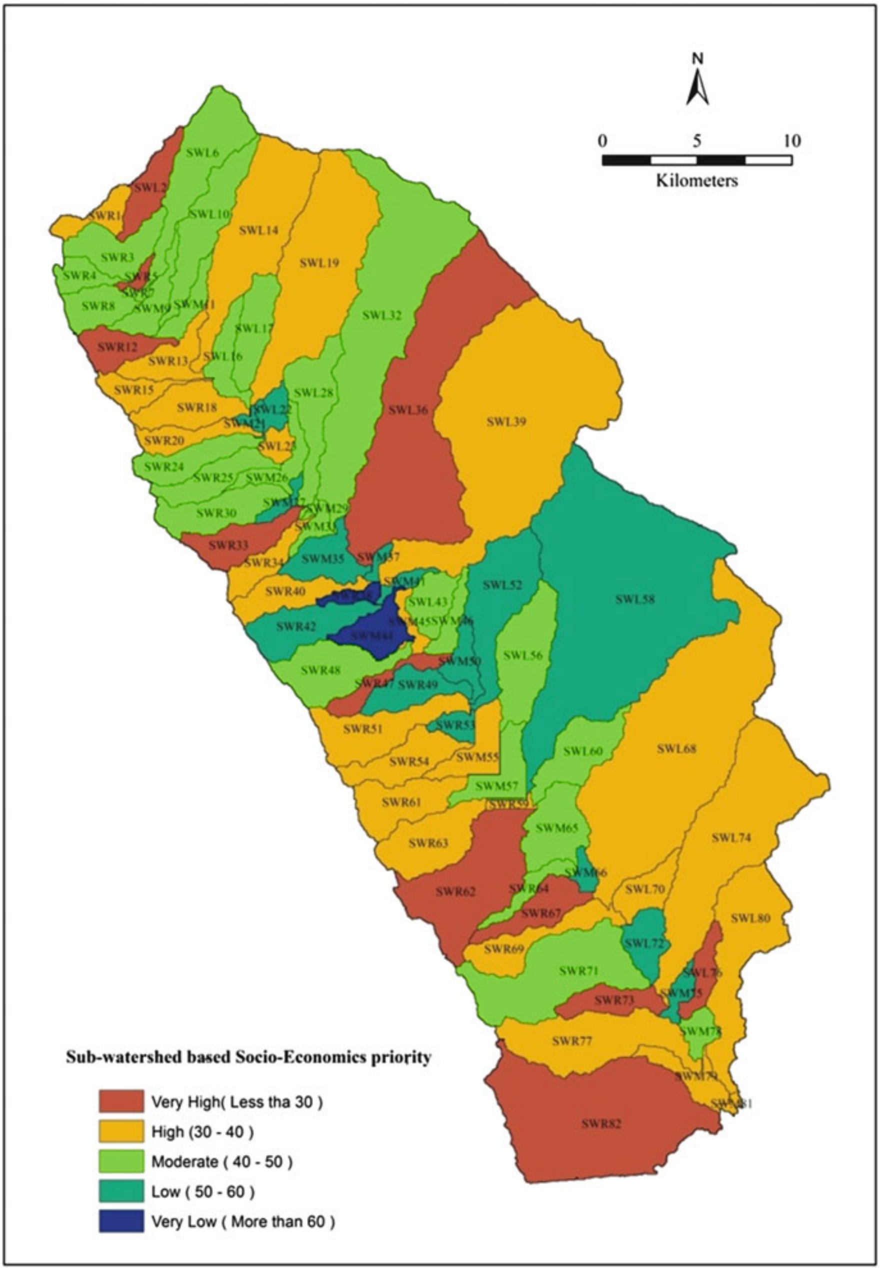

Fig. 3.8 Compound socio-economic indicators of the sub-watersheds in the Swan Catchment

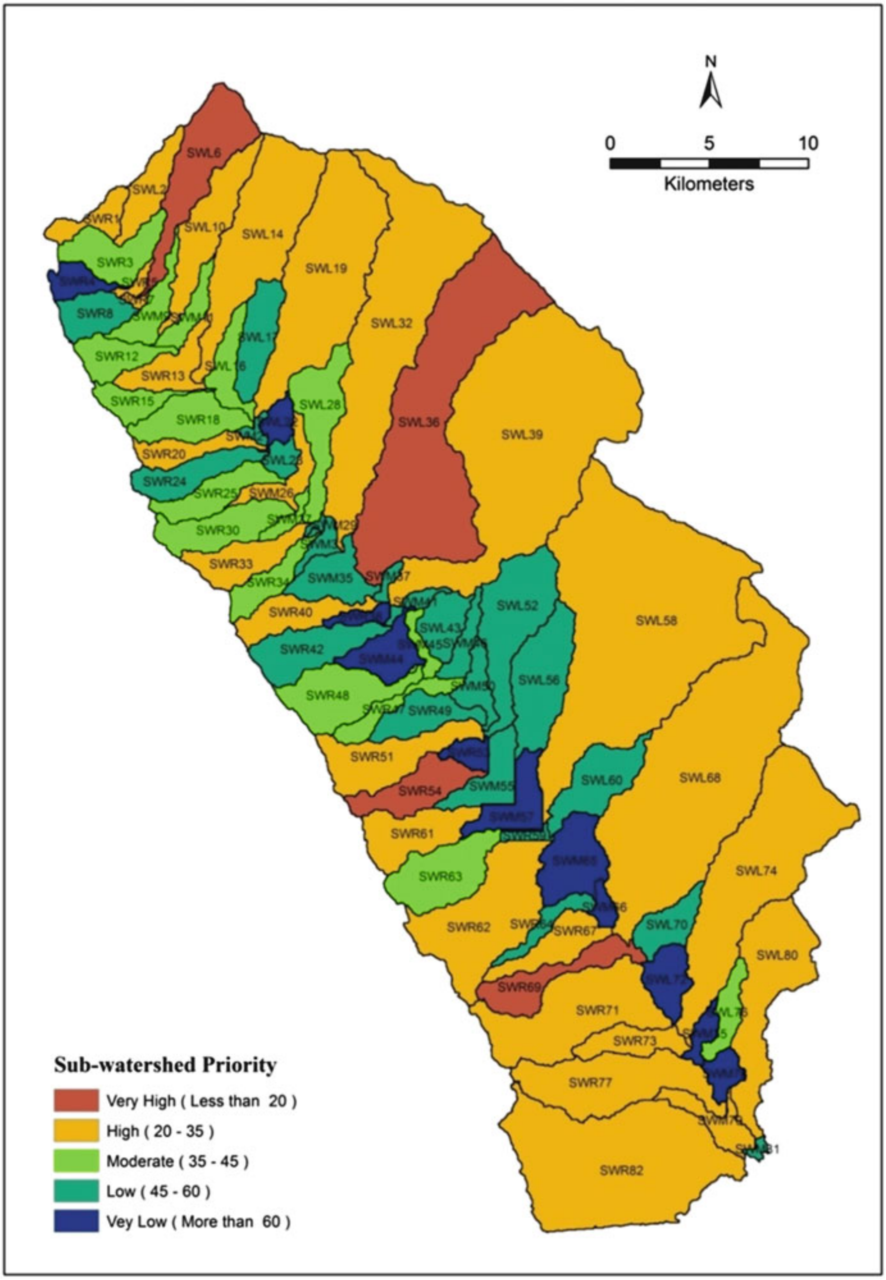

Fig. 3.9 Final priority of sub-watershed in the Swan Catchment

and SWM78. These watersheds consist of lower slopes, very low drainage density, stream frequency, texture ratio, high form factor, circulatory ratio and elongation ratio. These watersheds can be categorized under very slight erosion susceptibility zone and may need agronomical measures to protect the sheet and rill erosion.

3.5 Conclusion

Watershed development in India is no longer limited to scientifically determined methods of soil and water conservation, but has gone far beyond that, evolving instead into a form of *'Watershed Plus'*, which seeks to ensure not only the availability of drinking water, fuel wood and fodder for the poor, but also raise their income and employment opportunities through improvements in agricultural productivity, better access to markets, extension services, etc. Hence, integrated natural resource management and watershed development has become a larger paradigm for achieving sustainable development in the country. Based on morphometric, soil loss equation model and socio-economic analysis and their ranks, the sub watersheds have been classified into five categories as very high, high, moderate, low and very low in terms of priority for conservation and management of natural resources. The prioritization results that only 4 (5 %) sub-watershed falls under very high priority, 29 (35 %) sub-watersheds all under high priority, 17 (21 %) sub-watershed falls under moderate priority, 21 (26 %) sub-watershed falls under low priority, 11 (13 %) sub-watershed falls under very low priority on the basis of morphometric, soil loss equation model socio-economic indicators analysis. Hence these may be taken for conservation measures by planners and decision makers for local-specific planning and development.

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Chapter 4
Deglaciation and Impact of Extreme Rainfalls on Recent Relief Transformation of the Upper Pindari Valley: The Kumaun Himalaya, India

Zofia Rączkowska and Ramesh Ch. Joshi

Abstract The upper Pindari River Valley is situated in the southeast of the Nanda Devi massif in higher reaches of the Kumaun Himalaya. The satellite images were used as the background of the geomorphological mapping during field expeditions in 2012, 2013 and 2014. Particular attention was paid to the glacial relief within the valley floor, relief transformation after glacial retreat and morphogenetic processes responsible for relief transformation. The set of frontal and lateral moraine ridges is identified in the Pindari Valley bottom and their age is evaluated based on morphological features, historical data and relation to other landforms. Glacial landform is well preserved in the uppermost part of valley. In the lower parts it is completely or partly buried under talus cones, fluvioglacial cones and debris flows accumulation. It indicates rather high activity of morphogenetic processes in post glacial period and nowadays. The significant changes in the relief at present are effects of extreme rainfalls, as it occurred in June 2013. They encompass slopes and valley bottom, from the uppermost part up to mouth of the valley. Debris flows and landslides are triggered or rejuvenated on slopes, many new large undercuts occur along river channel, which is completely remodelled.

Keywords Glacial landform • Relief transformation • Extreme rainfall • Pindari Valley

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4.1 Introduction

The Himalayas, the world's highest mountains, are characterised by the alpine relief but of globally unique size of landforms. The evolution of the relief, of the glaciated part of the Himalayas and the role of monsoonal rainfall in relief transformation is still not fully explored. For this reason, geomorphological studies have been initiated in the upper Pindari Valley in the Nanda Devi massif.

In this region, glaciological investigations have been conducted for a long time. They have been focused on the extent of glaciers (among others Bose 1970; Nainwal et al. 2007; Bhambri et al. 2011; Mal and Singh 2013; Bali et al. 2011, 2013), which is a significant problem in the entire Himalayas (among others Bolch et al. 2012) due to glacial retreat and global warming. The first information on the Pindari glacier extent dates back to the mid-nineteenth century (Strachey 1847; Schlagintweit-Sakunlunski 1880), and glacial studies were conducted in various years in the entire twentieth century (among others Cotter and Brown 1907; Jangpangi 1958; Tewari and Jangpangi 1962; Ahmad and Saxena 1963; Tewari 1969, 1971, 1973). The studies are continued in twenty-first century as well as paleoglacial reconstruction (Bali et al. 2011, 2013; Rączkowska and Joshi 2014). Apart from direct measurements, learning about the relief of a glacier foreland is a source of information on the course of deglaciation and can be the basis for assessing the influence of other geomorphological processes on relief transformation. Glaciers are the main relief-forming factors in glaciated regions. However, rainfall is also a significant factor, particularly in the monsoon climate (e.g. Barnard et al. 2004, Bookhagen et al. 2005). The question concerning the role of these factors in relief transformation is therefore still open.

The aim of this article is presenting the features of the relief in the upper Pindari Valley in the highest part of the Himalayas. The particular attention is paid to the glacial relief within the valley floor, relief transformation after glacial retreat and morphogenetic processes responsible for relief transformation.

4.2 Study Area

The upper Pindari Valley is situated in the southeast of the Nanda Devi peak in higher reaches of the Kumaun Himalaya (Fig. 4.1). Nowadays, the glacier belt in the valley ranges from about 4000 m to over 7000 m a.s.l. In the uppermost part of the valley, the small transverse Pindari glacier emerges southwards from the névé field on the slopes of the Nanda Khat (6611 m a.s.l.) – Nanda Khot (6861 m a.s.l.) ridge at an altitude of about 5700 m a.s.l. The glacier snout is situated at approximately 3750 m a.s.l. It neighbours the mouth of the Changuch Glacier Valley, the snout of which is situated approximately 1 km inside the valley. In the region of Dwali at a height of approximately 2800 m, the Pindari Valley joins with the Khafni

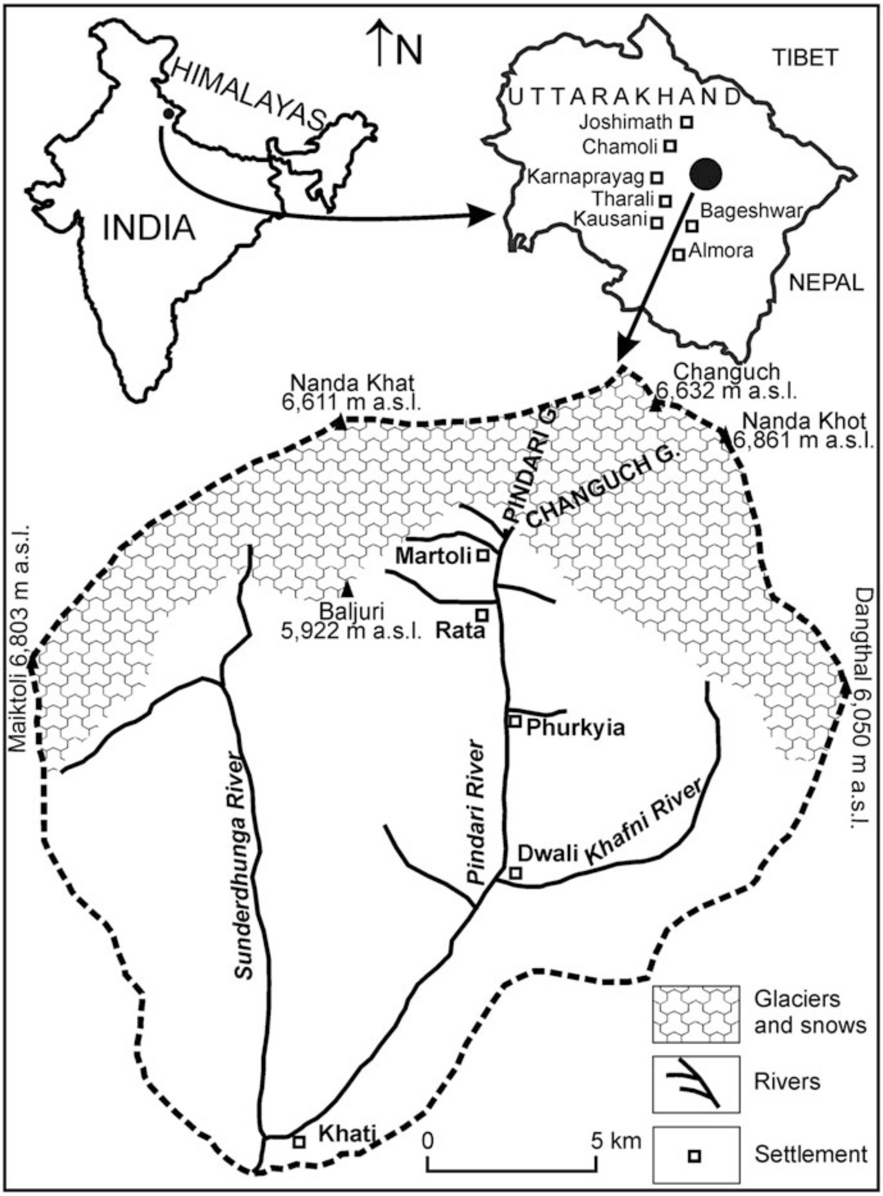

Fig. 4.1 Location of the study area

Valley. In the region of Khati, at approximately 2210 m a.s.l., the Sunderdhunga River enters the Pindari River from the west.

The Pindari Valley is situated in the Great Himalayas made of 10–20 km thick high-grade metamorphic rocks and gneissic granites which are intruded by lightcoloured granites of Central Crystalline Axis of Himalayan province. It is situated in the Trans Himalayan Thrust separated from the Lesser Himalayas by the Main Central Thrust (MCT). The lowermost section of the upper Pindari catchment is situated in the MCT zone and Outer Lesser Himalaya made of thick and vast sheets of metamorphic and granite rocks that cover Precambrian sedimentary and volcanic rocks (Valdiya 1998).

The geological structure is characterised by high lithological diversity, which is best visible in the uppermost sections of the valley situated within high-grade metamorphic carbonate and crystalline rocks including, among others, biotite-psammite gneisses, pegmatitic and granitic dyke intrusions, biotite shales, porfiroblastic shales, tourmaline and pegmatite shales, shales with granites and tourmaline-aplite granites (Gansser 1964).

The climate of the investigated region is characterised by long, severe winters (October–March) with snowfall brought by western masses of air. Being situated on the southern slopes of the Himalayas, the valley receives most of the rainfall from the monsoon current that penetrates the valley from June to September. The air temperature in winter is negative, and in summer it can reach 30 °C. According to Singh and Mal (2014), annual rainfall and monsoon rains have declined in high altitudes of Uttarakhand in the past decades whereas winter rainfall not shows distinct trends.

4.3 Data and Methods

The investigations were conducted during field expeditions in October 2012, 2013 and 2014. The information on the relief was obtained based on geomorphological mapping conducted on the background of satellite images generated with contour lines. The landforms were localised with the use of a GPS Garmin system. The mapping encompassed a 10-km-long part of the Pindari Valley floor ranging from the glacier snout to an altitude of approximately 3500 m a.s.l. (rocky gorge of the Pindari River). A geomorphological sketch was drawn for the lower section between the gorge and the Purkhyia mountain shelter. Additionally, the geomorphological effects of extreme rainfall from June 2013, observed along the Pindari River channel up to the site where it joins the Sunderdhunga River near Khati village, were registered.

The age of the youngest glacial landforms was identified by analysing the historical materials, topographic maps and satellite images from different time periods from the year 1968 to the present-day. The historical materials comprised old sketches from the mid-nineteenth century as well as old photographs and sketches with marked changes of the Pindari Glacier extent during the twentieth century.

4.4 Results and Discussion

4.4.1 Relief Asymmetry and Zonality

The uppermost part of the Pindari Valley is a glacial cirque formed by joint ridges and peaks of Nanda Khat (6611 m a.s.l.), Changuch (6632 m a.s.l.), Baljuri (5922 m a.s.l.), Panwali Doar (6663 m a.s.l.) and Pindari Kanda (Traill Pass 5700 m a.s.l.). This area is mostly occupied by glaciers. The upper Pindari Valley is a glacial trough filled with morainic and fluvioglacial deposits. In the region that was included in the geomorphological mapping, the upper edges of the glacial trough are situated at 4300–4200 m a.s.l. Above them, there are hanging glacial cirques, frequently situated in tiers. At present, they are completely or partially filled with glaciers (Fig. 4.2). The relief in this area is asymmetrical; the glacial cirques are extensive on the right of the trough, and on the left, the trough is flanked by nearly vertical rocky walls and slopes rising up to the ridges – the nunatak-like formations situated at an altitude of ca. 5000 m a.s.l. that separate the glacial trough of the Pindari Valley from the uppermost névé fields and hanging glacial cirques. The geological structure, including considerable lithological diversity and the position of the valley in relation to the inflow of air masses that bring rainfall, may have contributed to the asymmetry.

The bottom of the valley is mainly filled with glacial, fluvioglacial, fluvial and gravitational sediments (Fig. 4.2). Glacial landforms include a complex of ridges of lateral and frontal moraines that differ morphologically and morphometrically. From the eastern side, the glacial tongue adheres to the medial moraine with relative altitude of 200 m. In the sketches that date back to the mid-nineteenth century, only top of its ridge was visible. The ridge of lateral moraine, with relative altitude of 100–250 m, emerges nearly directly from the glacial snout on both sides of the valley. It was probably formed during the Little Ice Age, however Sharma and Owen (1996) dated similar forms in the Garhwal Himalaya on mid-Holocene. At an altitude of about 3550–3600 m a.s.l., it transforms into the zone of frontal moraines that consists of numerous ridges. The external, lower ridges in this zone are dated to 6 ka ± 1 ka (Bali et al. 2013). The slopes of the lateral moraine ridge facing the river are steep due to erosion and free of vegetation. Inside the zone enclosed with this noticeable ridge, there are lower ridges of frontal moraines (up to several meters high) from different, younger phases of glacial stagnation, of which the most prominent ridge is up to 20 m high and, according to historical data, formed in 1906 (Cotter and Brown 1907, 1925; Tewari 1973, Fig. 4.2).

Below the moraine complex, on the bottom of the valley to the right of the river, there is a visible 20-m-high ridge of the lateral moraine that descends nearly to the rocky gorge of the river channel. On the left side of the valley at a similar altitude, there are slight fragments of the corresponding lateral moraine ridge buried under debris brought down the slopes of the trough due to fluvioglacial and gravitational processes as well as debris flows. The lateral moraine ridge at the right side terminates approximately 5 km below the glacial snout and transforms into a frontal

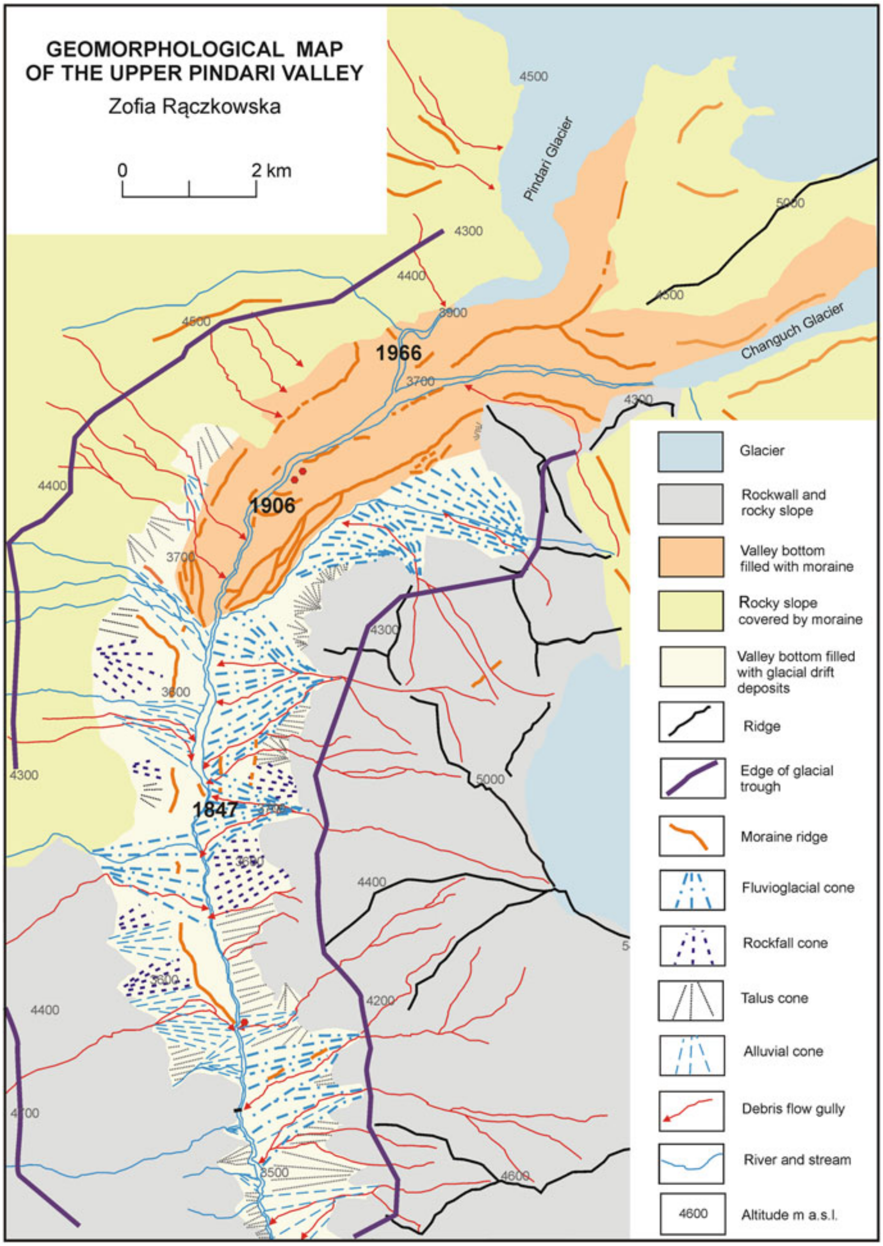

Fig. 4.2 Geomorphological map of the upper Pindari Valley. Labels on the map mark extent of the Pindari Glacier in 1847, 1906, 1966

moraine. The ridge was formed in the Late Glacial period since its distance from the front of Pindari Glacier is similar to the formations in the Mandakini Valley (Garhwal Himalaya) (Mehta et al. 2012). According to OSL the ridge is dated to 25 ka ± 2 ka (Bali et al. 2013). In the upper left part of the valley, approximately 1.5 km from the end of the lateral-frontal moraine ridge described above, there is a slight fragment of the ridge of a lateral moraine. It is located near the river channel, and rises to a height of 3–10 m. According to a sketch drawn by Strachey (1847), the Pindari Glacier could reach this area in the first half of the nineteenth century (Fig. 4.2). However according to Bali et al. (2013) it is of the same age as ridge of lateral-frontal moraine on the right side of the river.

The glacial relief is relatively well-preserved only in the uppermost sections of the valley where it has been poorly transformed by the periglacial processes. In the lower parts of the valley, the glacial relief on the valley floor is completely or partially buried under fluvioglacial cones, talus heaps, talus and rockfall cones as well as alluvial cones formed by the deposition of debris flows. These landforms differ in the structure and texture of sediments that forms them. They also vary in their sizes and inclination. The largest fluvioglacial cones are several hundred meters long and wide. Most of them are dissected with debris flows gullies, the depth of which vary and reaches a dozen or so meters. The most prominent debris flows gullies are marked on the map (Fig. 4.2). Fresh rocky material can be observed on the majority of the cones of various origins. This indicates a considerable activity of morphogenetic processes both after the Pleistocene glaciers retreated and at present. The covering of the glacial relief by debris flows and fluvial processes directly after glacier recession was emphasised in the studies conducted on the northern side of the Nanada Devi massif by Barnard et al. (2004).

Basically, several zones can be distinguished in the relief of the upper part of the valley. The zone above 5000 m includes névé fields and glaciers as well as hanging glacial cirques separated by the nunatak-like ridges. Between this zone and the valley floor filled with debris of various origins, i.e. at the altitude between 3700 and 3900 m, there is the zone of glacial trough slopes and edges formed by rocky walls and slopes or rocky slopes covered with glacial or fluvioglacial sediments. They are cut with chutes or gullies for water drainage from the hanging valleys, the majority of which have their glaciers.

4.4.2 Recent Deglaciation

Most of the Himalayan glaciers are currently retreating (Bolch et al. 2012). The recession rate varies even within individual massifs. According to Majewski and Jeschke (1979), the glaciers in the Garhwal Himalaya have been continuously retreating since the year 1850, and the recession of the Pindari Glacier has been the most prominent – in the years 1850–1979, it retreated by 2600 m. In the nineteenth century, the position of the Pindari and other glaciers in the Pindari Valley was similar to their current location, but their extent and thickness were

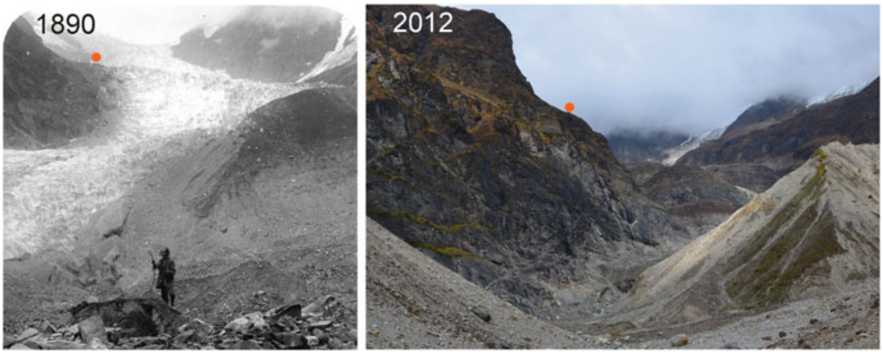

Fig. 4.3 Change of vertical range of the Pindari Glacier. Historical photo was taken by Boeck (1900). *Dot marks* the same place

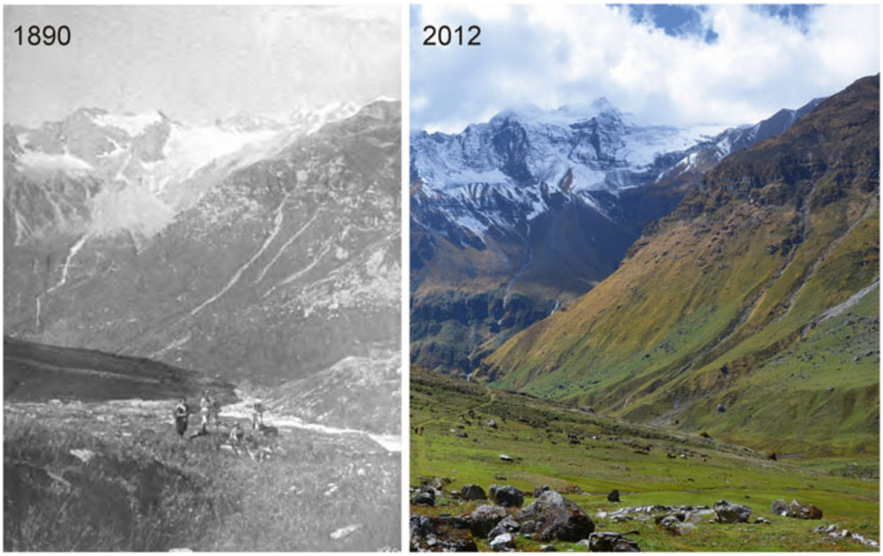

Fig. 4.4 Glaciers on Baljuri peak (5922 m a.s.l.) viewed from Martoli. The extent of glaciers decreased considerably between 1890 and 2012 (Historical photo was taken by Boeck (1900))

much greater, which can be assessed by comparing historical and contemporary images (Figs. 4.3 and 4.4).

The historical sketches that present the extent of the Pindari Glacier in various time periods in the last 200 years enabled to assess the rate of the glacier retreating (variable in time) (Table 4.1) and estimate the age of certain moraine ridges (Fig. 4.2).

Until 1950s, the rate of the Pindari Glacier recession was twice as rapid as in the later forty years. In 1958, the Pindari and Changuch Glaciers had a common tongue, but separated shortly afterwards, which was observed in 1966 by Tewari (1973).

Table 4.1 Rates of the Pindari Glacier recession from the mid-nineteenth century (after Tewari 1973; Bali et al. 2011, 2013)

Period	Total recession (m)	Duration (years)	Rate (m year^{-1})
1845–1906	1600	61	26.23
1906–1958	1040	52	20.00
1958–1966	61	8	7.62
1966–2007	262	41	6.39
2007–2010	117	3	39.00

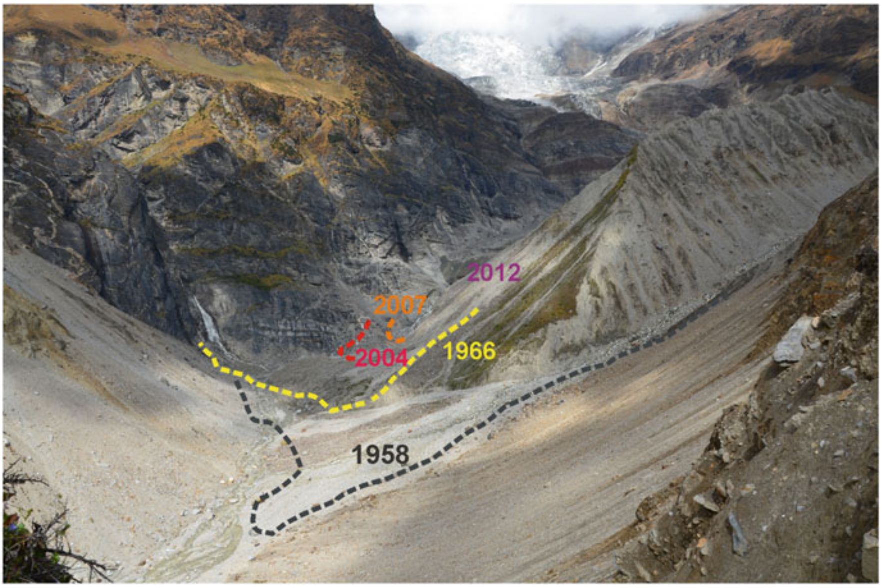

Fig. 4.5 The recent changes of the Pindari Glacier front extent based on data from field studies and relevant literature

The accumulative glacial relief from this youngest period is relatively poorly preserved (Fig. 4.5). Below the Pindari Glacier snout, on the left side, on the slope of an older medial moraine, there is a ridge of a lateral moraine that is 7–10 m high and corresponds to the probable extent of the glacier in the 1960s. There are no moraines on the right side since the narrow glacial tongue hangs from a rocky step and adheres to the nearly vertical rocky wall. The frontal moraine ridges from the 1950s and younger have been probably washed out by fluvioglacial waters from the Changuch and Pindari Glaciers. The remainders of them may be low and poorly visible trails/ridges of morainic material or large boulders (Fig. 4.5). But results of direct observations indicate that the recession of the Pindari Glacier rapidly increases in the last decade. The rate of the recession is from several – to tenfold greater than in the second half of twentieth century (Bali et al. 2013).

4.4.3 Impact of Extreme Rainfall on Present-Day Relief Transformation

Currently significant relief changes in the non-glaciated section of the valley are the effects of summer extreme rainfalls. They cause changes both on the slopes and on the valley floor, from its uppermost parts to the mouth. The strong monsoonal control of the dynamics of geomorphic processes in this part of the Himalayas is emphasised by various authors (among others Barnard et al. 2004). The Indian summer monsoon provides most of the annual precipitation between June and August. In this period, the rainfall total amounts to approximately 1550 mm, but can vary in individual years. For instance, Dobhal et al. (2013) reports that the total of summer monsoon rainfall in the Kedarnath region (west of the Pindari Valley) ranged from 734 mm to 1685 mm in individual years between 2007 and 2012.

Summer rainfall activates mass movements on the slopes, mainly debris flows and landslides. Due to such activation, the slopes are fragmented and large amounts of material are transported across the entire slope system from the ridge to the valley floor and to the river channels. The presence of fresh debris flow gullies as well as levee and alluvial cones that accompany them attests to the common occurrence of debris flows and mud flows. The slopes are also modelled by weathering and falling processes favoured by severe thermal conditions. Talus and rockfall cones are not as frequent or as large as alluvial and fluvioglacial cones, which might suggest lower effectiveness of falls and slumps. Rockfall may be triggered by thermal and lithological conditions as well as earthquakes since the region is seismically active and numerous authors highlight the association of large-scale mass wasting with this cause (e.g. Ambraseys et al. 1981; Owen et al. 1995).

The greatest relief transformations result from rainfalls that are extraordinary both in terms of their totals and intensity (Starkel 1972; Starkel and Basu 2000; Bookhagen 2010). Such rainfall occurred in the investigated region in June 2013 and peaked on 16–18 June (Table 4.2). The data of rainfall totals came from the nearest meteorological stations to the area of investigation due to the absence of stations directly in the valley. The variability of daily precipitation total in the analysed stations must be emphasised. It indirectly suggests its spatial diversity which is also one of the significant factors that influence the geomorphological

Table 4.2 Daily rainfalls at the nearest meteorological station to the upper Pindari Valley (Government of India. . .2013, cf. Fig. 4.1)

Station	Rainfall (mm)		
	16 June	17 June	18 June
Joshimath	<65	110	80
Chamoli	<65	80	100
Karnaprayag	90	90	80
Tharali	<65	170	80
Bageshwar	<65	160	<65
Kausani	<65	210	<65
Almora	<65	90	100

Fig. 4.6 Relief changes on the slopes in the uppermost part of the Pindari Valley after heavy rainfalls in June 2013

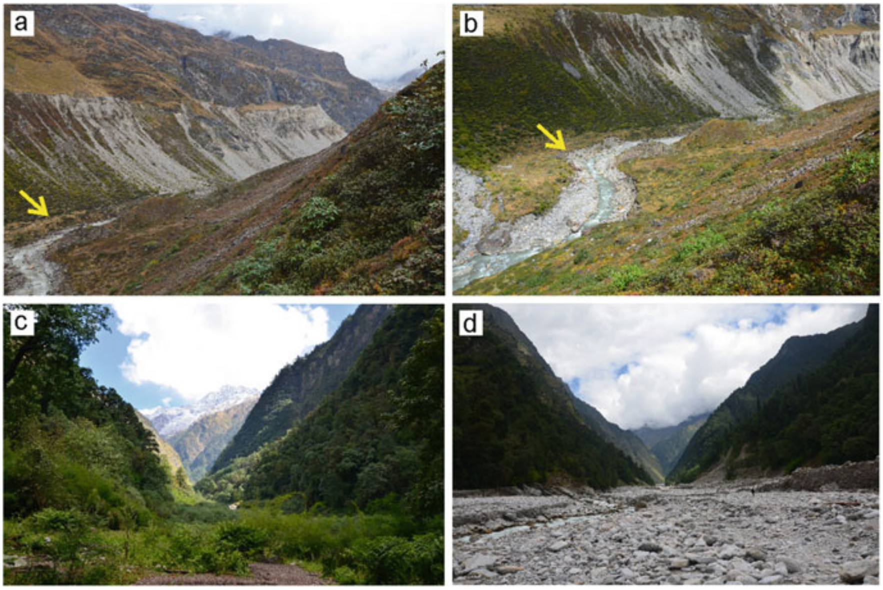

Fig. 4.7 Change of the Pindari River channel after the flood in June 2013, (**a**) section in the uppermost part of the valley in 2012, (**b**) section in the uppermost part of the valley in 2013, (**c**) section below Dwali in 2012, (**d**) section below Dwali in 2013

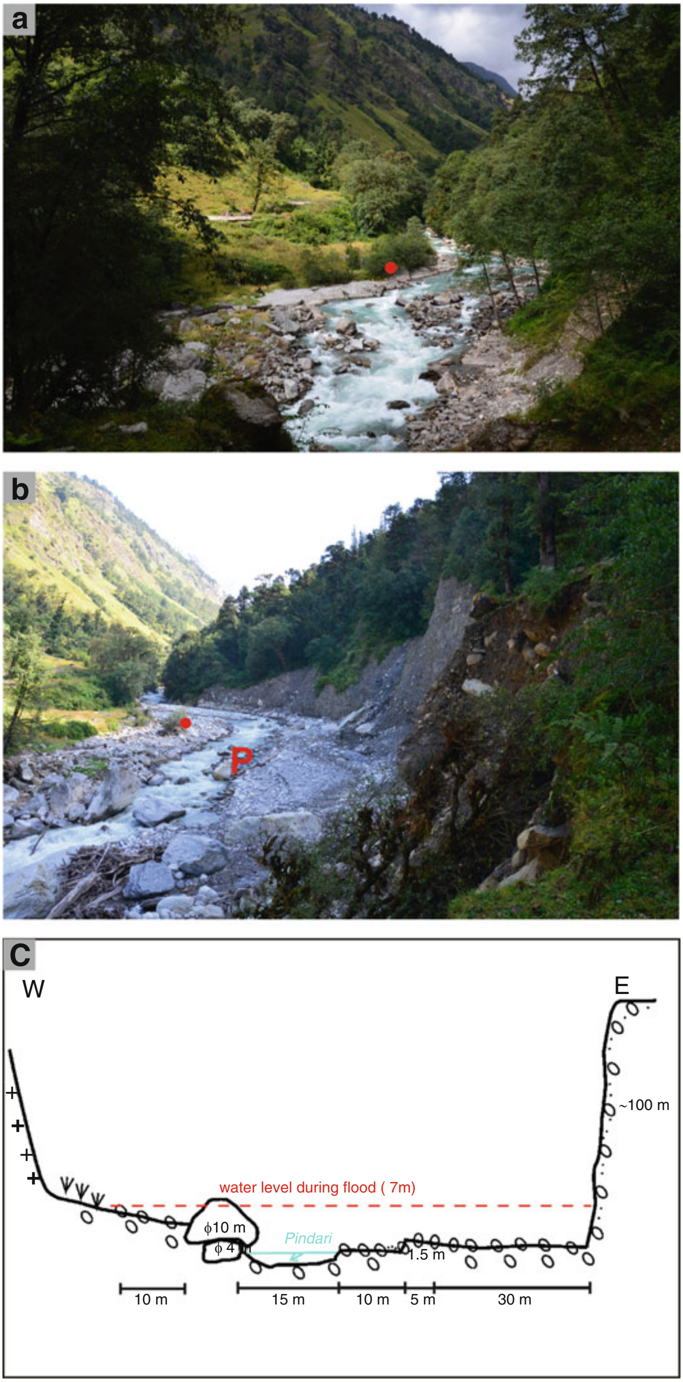

Fig. 4.8 Changes of the Pindari River channel about 5 km above Khati village, (**a**) 2012, (**b**) 2013, (**c**) cross profile of the channel after the flood in 2013, ***P*** cross profile location. *Dot marks* the same rocky block

effects of precipitation. According to the personal communication, the highest intensity of rainfall in the Malla Dhar region (the middle part of the valley located approximately 5 km above Khati village) on 16/17 June could reach 300 mm h^{-1}.

The greatest changes of rainfalls in June 2013 occurred on the bottom of the Pindari Valley below its confluence with the Khafni Glacier Valley. Their unique character is demonstrated by the remodelling of all debris flows gullies and other erosional gullies on the slopes in the uppermost part of the Pindari Valley (Fig. 4.6). No such remodelling was observed following the monsoon rain in 2012 when similar geomorphological effects were common in the Lesser Himalaya. Moreover, the cones at mouths of these gullies also underwent remodelling. This can indirectly

Fig. 4.9 View of the mouth of Khafni River near Dwali. Lower photo, on the right, shows the front of large landslide

indicate that heavy rainfall occurred in the uppermost part of the mountains in particular/as well. In the Pindari River channel in this part of the valley, the channel widened and bank undercuts reappeared. The changes were relatively slight compared to the part below the Dwali after it joins the Khafni tributary (Fig. 4.7a, b). In this fragment, the valley bottom was transformed on its entire width. It functioned as a river bed during river swelling (Fig. 4.7c, d). The undercutting of the valley slopes by waters flowing in the flood channel caused reappearance or appearance of bank undercuts along its both banks. They reach a height of up to 100 m.

Furthermore, landslides became active on the slopes. The largest of them, which occurred on the western slope, is of a gigantic size. The main scarp is several hundred meters high, the thickness of the colluvia is similar, and its front with the width of 0.5 km is cut by a large gully for mudflow which was still active in autumn 2014.

Such great valley bottom transformation was a consequence of a considerable increase in the level of water by approximately 7 m, which was estimated on the basis of geomorphological landforms, i.e. terrace levels which were formed in the channel after river swelling (Fig. 4.8). Moreover, it was also influenced by the presence of rocky material in the water. The rocky material was delivered by large landslides of weathered debris during swelling events in the mouth of the Khafni Valley which, by contrast with the Pindari Valley, underwent complete remodelling (Fig. 4.9).

As a result of the swelling three levels were formed within the channel alluvia with the altitude of 7–8 m, 4 m and 1.5–2 m above the present water surface. The highest level is only fragmentarily preserved in the form of inliers, and the lower levels are separated from each other by marked edges (Fig. 4.10).

Fig. 4.10 Relief of the Pindari River channel after the flood in June 2013. *Arrows* indicate three erosional levels

4.5 Conclusions

The relief of the Pindari Valley is typical of high mountains. The main landforms were created by glaciers. The relief asymmetry due to lithological and climatic conditions is well developed. Its altitudinal diversity is observed as well.

The glacial relief has been intensively transformed since glaciers retreat. This is caused by a wide range of geomorphological processes and leads to the burying of the glacial landforms and deposits in the valley floor except for the youngest or presently occurring ones.

Summer monsoon rainfalls of high totals and intensity seem to be the most important factors that affect present-day relief transformation in the areas that are not covered by glaciers.

Acknowledgments This paper is the outcome of research cooperation between Institute of Geography and Spatial Organization, Polish Academy of Science and the Indian National Science Academy. The authors would like to thank Dr. Anita Pande and Ph.D. students: Dipak Kumar and Naresh Semwal from the University of Nainital as well as Mr. Ishwar Singh Danu from Watcham for their help during the field studies.

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Chapter 5
Riverbeds Level Changes in the Margin and Foreland of the Darjeeling Himalaya During the Years with a Normal Monsoon Rainfall

Łukasz Wiejaczka

Abstract The study determines the scale and direction of changes in the riverbeds level within the Darjeeling Himalaya and its foreland, due to overlapping of natural and anthropogenic factors. The analysis is based on the monitoring conducted in the period 2011–2014. Three adjacent rivers, the Lish, Gish and Chel, were selected for the study, tributaries of the Teesta River (a tributary of the Brahmaputra). The results show that the alluvial bed of the Lish and Gish rivers in the Himalayan foreland, tend to show an aggradation of about 3 cm year^{-1} and 0.5 cm year^{-1} respectively. On the other hand, in the mountain part of the Chel River with a rocky bottom and in the alluvial riverbed in the Himalayan foreland, a trend was noted for the channel incision of about 1 cm year^{-1} and 5 cm year^{-1} respectively. Analysis is of great importance in the context of the assessment of the effects of possible catastrophic floods.

Keywords Channel morphology • Aggradation • Himalayas piedmont • India

5.1 Introduction

Himalayan rivers have highly dynamic environment with extreme variability in discharge and sediment load and are characterized by frequent changes in shape, size, position and planform (Kale 2002). The main factor affecting the morphology of riverbeds in the Himalayas and their foreland are frequency and magnitude of floods caused by high rainfall. Their annual totals fluctuate between 2000 and 4000 mm in the margin of the Western and Central Himalayas and between 4000 and 6000 mm in the margin of the Darjeeling Himalaya located within Eastern Himalayas (Soja and Starkel 2007; Bookhagen 2010). The scale of morphological

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transformation in channels also differs, depending on the lithology, relief, size of the catchment, length and gradient of the river as well as on the human activity (Starkel and Basu; 2000; Lavé and Avouac 2001; Price and Leigh 2006; Pike et al. 2010).

Bedrock incision is a common morphological process in the Himalayan riverbeds, it can result from different processes: mechanical wear by rolling and saltating bedload or by suspended load, plucking, weathering, and dissolution, or cavitation. According to estimates, the rate of rivers' incision in central Nepal varies from 1.0–1.5 cm $year^{-1}$ in Siwaliks to few mm in the Lesser Himalayas and 0.4–0.8 cm $year^{-1}$ in the Higher Himalayas (Lavé and Avouac 2001). The rate of the incision depends also on the uplift rate estimated for the Eastern Himalayas on 0.05–0.4 cm $year^{-1}$ (Nakata 1972). Only the greatest rivers like Brahmaputra or Teesta may follow the uplift rate in this region (Starkel 1989). Deposition of material carried-out from the mountains is, at the same time, a typical morphological process in the Himalayan foreland (Goswami 1985; Sarma 2005; Tamang and Mandal 2015).

Increased aggradation of the river channels in the Himalayan foreland leads to channel shallowing (Sarma 2005). On the other hand, the extraction of bed material by local communities during the dry season leads to their dredging (Starkel and Basu 2000; Tamang and Mandal 2015). Such human activities directly alter channel geometry, as well as the dynamics of water and sediment transport (Wohl 2006).

A good example of area with intensive rate of denudation and deposition is the margin and piedmont of the Darjeeling Himalaya. The area drained by the Teesta River, a largest Himalayan right-bank tributary of the Brahmaputra, receives one of the highest rainfall along the whole Himalayan range. Every year, at the piedmont, the Teesta discharge may reach 3000–5000 $m^3 s^{-1}$, but every dozen of years, during devastating floods, discharge can be 3–4 times higher. That cause transformation of the channel morphology and riverbed aggradation (Starkel 1972; Starkel et al. 2008).

The purpose of this study is to determine the scale and direction of riverbeds level changes in the Darjeeling Himalaya and its foreland, as caused by natural and anthropogenic factors. Three adjacent tributaries of the Teesta River were selected for the detailed cross-section measurements. Analysis encompassed period 2011–2014, when rainfall was closed to long-term averages.

5.2 Study Area

The study area is located in India in the Darjeeling Himalaya and their foreland drained by the Teesta River (Figs. 5.1 and 5.2). The southern margin of the Darjeeling Himalaya is elevated to 2000–4000 m a.s.l. and dissected by valleys up to 1500 m deep. It is built mostly of metamorphic rocks – Darjeeling gneisses, Daling schists and quartzites, Damuda sandstone with quartzites and shales (Acharyya 1980). The Main Boundary Thrust separates them from the Siwaliks

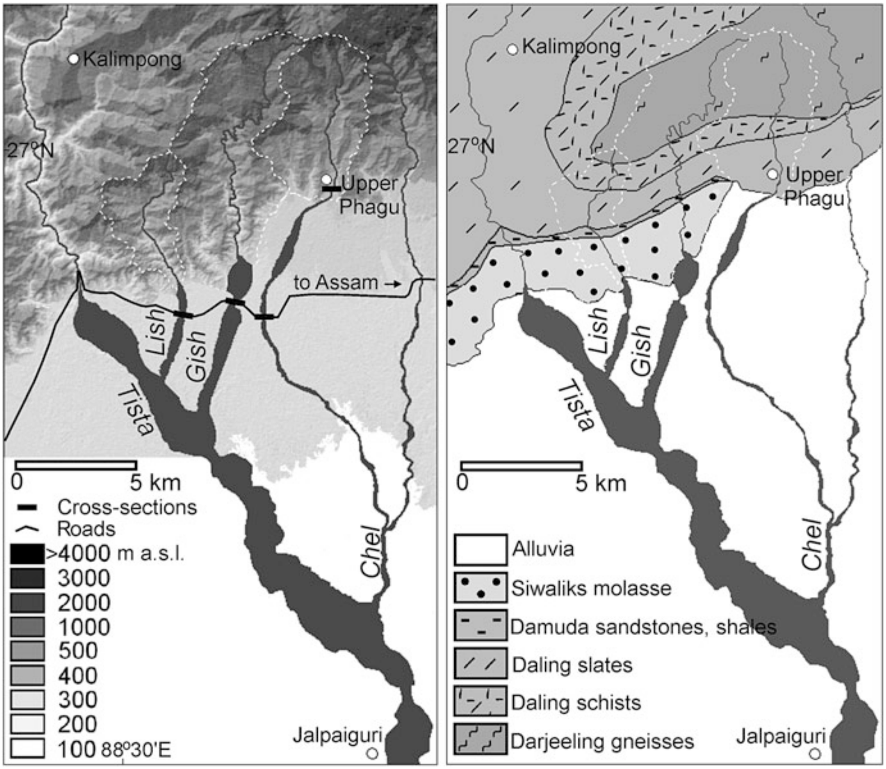

Fig. 5.1 Location (*left*) and geology (*right*, by the author on the basis of Acharyya 1980) of study area

built of molasse beds of sandstones, conglomerates and mudstones. On its foreland is the piedmont zone called Duars. This area represents a system of Quaternary fans decreasing in elevation from 200 to 300 m a.s.l. at the base of the mountain to about 100 m a.s.l. over a distance of 15 km (Nakata 1972; Chakraborty and Ghosh 2010). The fan surface is fragmented by the wide braided channels of the Teesta and its tributaries.

The Lish River is the first large left-bank tributary of the Teesta River in the piedmont zone. The total length of the river is 20 km and the catchment area is 64 km^2, of which 51 km^2 is a mountainous area, where the highest peaks reach 1820 m a.s.l. (Starkel and Basu 2000; Starkel et al. 2008, Table 5.1). The river network has a dendric pattern. Within the twentieth century, forest cover in the Lish mountainous catchment was reduced from 75 to 67 % at the expense of agriculture, built up and quarrying coal area increase. The area affected by landslides is about 9.7 % (Basu and Ghatowar 1990; Prokop and Sarkar 2012). Below the mountains, there extends an alluvial fan of a length of about 10 km and a width of 3–5 km, narrowing at the site of two bridges (a rail and a road one) on a national highway running between West Bengal and Assam.

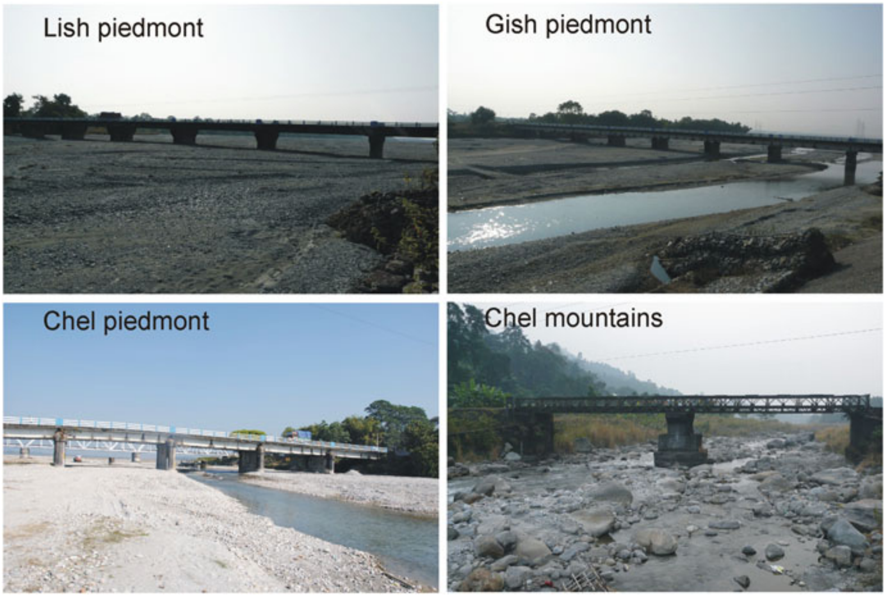

Fig. 5.2 Channels of the analyzed rivers at the location of measuring cross-sections in 2014

The Gish River is a second left-bank tributary of the Teesta River within the piedmont zone with a total length of 41 km and a catchment area of 201 km^2 (including 157 km^2 of mountains). The maximum height of the peaks in the catchment area reaches 2370 m a.s.l. Within the last century forest cover decreased from 83 to 78 % at the expense of agriculture, built up and quarrying coal area increase. The area affected by landslides is about 5.9 % (Basu and Ghatowar 1988; Prokop and Sarkar 2012). The length of the alluvial fan in the foreland of the mountains is up to 15 km, the width of it is 2.5 km.

The Chel River is the third in the order left-bank tributary of the Teesta River with a total length of 63 km (16 km in the course of a mountain range, catchment area of 97 km^2). The highest peaks within the catchment reach 2650 m a.s.l. The Chel River has several small tributaries between the edge of the mountains and the outlet to the Teesta River. Within the last century forest cover decreased from 68 to 52 % at the expense of agriculture and settlement area. The area affected by landslides is less than 1 %.

The climate is subtropical monsoonal, with the warm rainy season spanning from June to October and the dry cooler season from November to May. The mean annual air temperature reaches 23 °C, and fluctuates between 16 °C in winter (January) and 28 °C in summer (August). The marginal part of the piedmont belt (up to 5 km wide) and frontal zone of the Darjeeling Himalaya at elevations between 300 and 600 m a.s.l. receives about 4000–6000 mm rainfall annually. Then rainfall decreases northwards to below 2000 mm at 10 km from the mountain front. About 80 % of the annual rainfall occurs between June and August. During

Table 5.1 Characteristic of rivers draining the Darjeeling Himalaya and their piedmont (After Dutt 1966; Starkel et al. 2008; Prokop and Sarkar 2012 and author calculations)

River	Mountain catchment (km^2)	Forest area (%)	River gradient in mountains (‰)	River gradient in piedmont (‰)	Maximum discharge (m^3s^{-1}).	Minimum discharge (m^3s^{-1}).	Annual rainfall in catchment (mm)
Lish	51	66.5	111.0	13.1	254.7	0.25	4877
Gish	157	77.8	60.8	11.3	630.2	0.08	5385
Chel	97	52.2	156.6	9.5	184.5	0.06	6096

this period, few days of rainfall, exceeding 100 mm day^{-1}, is observed every year (Soja and Starkel 2007; Bookhagen 2010).

Several days of high continuous rainfall cause regional floods every 20–30 years (Starkel and Basu 2000; Sarkar 2008). During such events, the water level rises in the river channels up to 5–6 m and a heavy sediment load is deposited on the floodplains (Dhar and Nandargi 2000). In the past three decades, the riverbeds along the foreland of the Himalayas have experienced aggradations of about 6 cm $year^{-1}$ in the case of the larger trans-Himalayan Teesta, and between 9 and 11 cm $year^{-1}$ in the case of the smaller Lish and Gish (Sarkar 2008).

5.3 Material and Methods

The analysis is based on the results of fourfold morphometric measurements of the Lish, Gish and Chel riverbeds level, at four designated cross-sections (Figs. 5.1 and 5.2). Three cross-sections were located in the foreland of the mountains along the bridges on the national road connecting West Bengal and Assam in the distance of approx. 3 km (Lish), 4 km (Gish) and 11 km (Chel) from the front of the Darjeeling Himalaya. Additionally, one cross-section of the Chel River was selected along the road bridge located at the mountainous part of the catchment, 2 km above the Himalayan front. Measurements were made every year in late November and early December in the post-monsoon season (at the beginning of the dry season). The distance between the riverbed and the bottom bridge bases (as a benchmark) was measured with a tape, which allowed for the recognition of the scale and direction of changes of the channel bed level. Measurements of the channels in cross-sections located in the Himalayan foreland in the Lish, Gish and Chel rivers were performed every 5 m, while in the narrower profile in the mountain part of the Chel River, every 2 m.

The location of the cross-sections along the bridges was determined by the expected theoretically smallest scale of human impact on the riverbeds. In accordance with the regulations of the West Bengal Government, no extraction of minerals shall be allowed within 200 m of both sides of any river bridge (Tamang and Mandal 2011). Basing on the above statement, the riverbed in the immediate vicinity of bridges should keep the natural condition.

5.4 Results

5.4.1 Characteristics of the Lish, Gish and Chel River Channels at the Cross-Sections

The Lish riverbed at the location of the cross profile is artificially narrowed to a width of 90–150 m for the construction of two bridges, a road and a rail one, from West Bengal to Assam (Figs. 5.1 and 5.2). Narrowing of the channel at the location of the cross-section reaches 550 m and 700 m in relation to the width of the channel at a distance of 1 km above and below the road bridge. The Lish channel was dry at the time of measurements.

The Gish riverbed is artificially narrowed at the location of the measurement cross-section to about 100–135 m. The narrowing of the channel reaches approx. 1200 m and 1800 m in relation to the width of the channel at a distance of 1 km above and below the road bridge. The prevailing bed material is sand and gravel with a diameter up to about 10 cm. The process of extracting material from the river above and below bridges by local population is noted during dry season. Flowing water up to 10 m width and up to 0.5 m depth was observed during the measurements.

The Chel channel in the Himalayan foreland (Fig. 5.2), at the cross-section is 130 m wide, artificially narrowed, as in the case of the Lish and Gish rivers. Narrowing of the channel reaches approx. 300 m and 400 m, with respect to the width of the channel at a distance of 1 km above and below the road bridge. The braided channel is covered, as in the case of the Lish and Gish rivers, by sand and gravels with a diameter up to 15 cm. Flowing water with a width of approximately 10 m was observed in the course of the measurements. Massive bed material extraction is conducted in the channel of the Chel River. In the mountainous part, the Chel riverbed, at the location of the cross-section is 36 m wide. The bed of the channel, cut mainly in metamorphic rocks is covered by boulders with a diameter up to few meters.

5.4.2 Riverbeds Level Changes of the Lish, Gish and Chel in 2011–2014

The Lish riverbed level shows a rising tendency in 2011–2014 (Fig. 5.3, Table 5.2). The depth of the bed in 2011 ranged from 3.20 to 4.30 m. In 2014, the depths of the bed of the channel were in the range of 3.15–4.15 m. Progressive rising of the

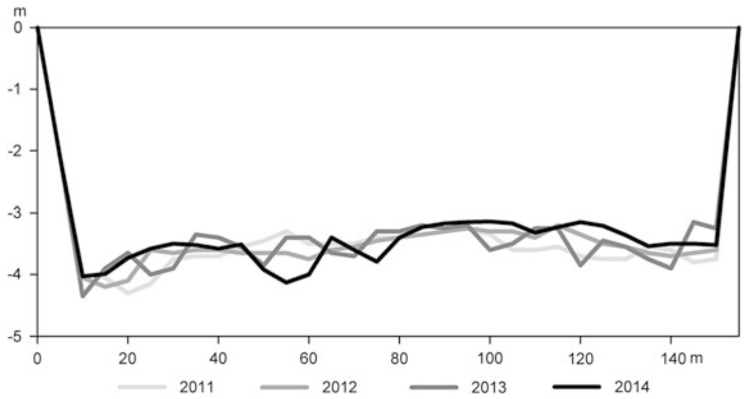

Fig. 5.3 Cross-sections of the Lish riverbed within the Darjeeling Himalaya foreland in 2011–2014

Table 5.2 The changes of the Lish, Gish and Chel riverbeds level (m) in the period 2011–2014

River	Depth of channel	2011	2012	2013	2014	Difference between 2011 and 2014
Lish	Average	3.62	3.57	3.55	3.51	0.11
	Minimum	3.20	3.20	3.15	3.15	0.05
	Maximum	4.30	4.20	4.35	4.15	0.15
Gish	Average	5.85	5.83	5.84	5.83	0.02
	Minimum	5.30	5.15	5.10	5.05	0.25
	Maximum	6.75	6.95	6.75	6.70	0.05
Chel (piedmont)	Average	6.21	6.05	6.23	6.32	–0.11
	Minimum	5.15	5.20	5.25	5.25	–0.10
	Maximum	7.80	7.25	6.95	7.20	0.60
Chel (mountains)	Average	5.74	5.72	5.74	5.77	–0.03
	Minimum	5.25	5.35	5.40	5.45	–0.20
	Maximum	6.45	6.35	6.20	6.30	0.15

maximum depth in subsequent years indicates slow channel shallowing. This process occurs uniformly in different parts of the measurement profile because raising and lowering of the channel bed takes place up to about 0.70 m year^{-1}. The average depth of the riverbed in 2011 amounted to 3.62 m, while in subsequent years, this value decreased by about 3 cm year^{-1} up to 3.51 m in 2014.

The Gish riverbed also show a tendency to raise their level over the 4 years (Fig. 5.4, Table 5.2). The depth of the channel in 2011 ranged from 5.30 to 6.75 m. In 2014, the depth of the bottom was in the range of 5.05–6.70 m. In the course of these values a trend towards channel shallowing have been noticed. In different parts of the cross-section alternating raising (up to 1.30 m) and lowering (0.95 m) of the channel bed occur. The difference observed between the average depth of the

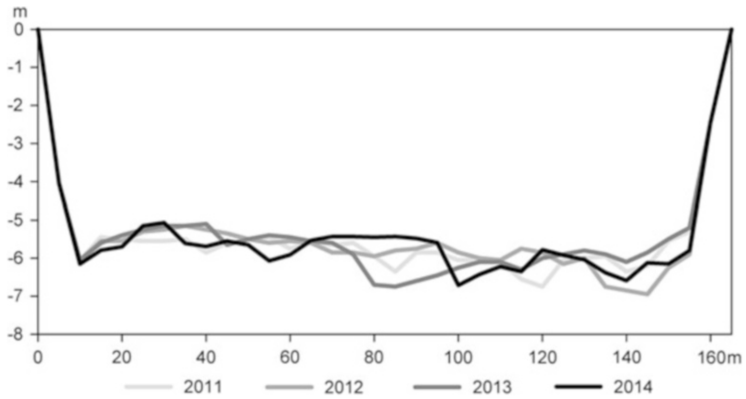

Fig. 5.4 Cross-sections of the Gish riverbed within the Darjeeling Himalaya foreland in 2011–2014

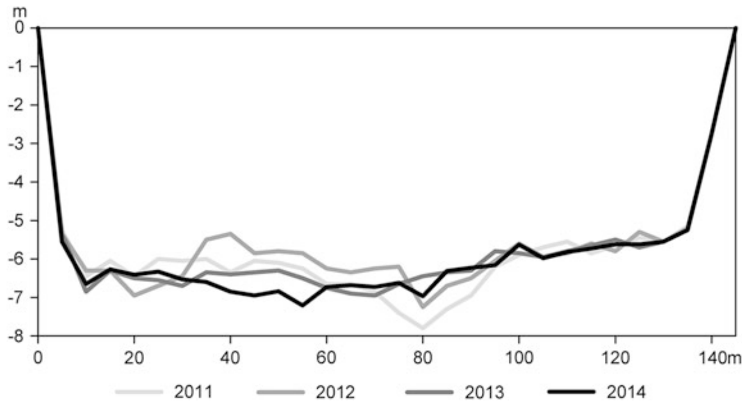

Fig. 5.5 Cross-sections of the Chel riverbed within the Darjeeling Himalaya foreland in 2011–2014

bottom of the channel in 2011 and 2014, only 2 cm, shows that the process of the Gish riverbed shallowing is slower, as compared to the Lish River.

The changes of the Chel riverbed level in the Himalayan foreland were more complex than in the Lish and Gish rivers at the same period (Fig. 5.5, Table 5.2). The depth of the Chel riverbed in 2011 ranged from 5.15 to 8.30 m. In 2014, the depth of the channel was in the range of 5.25–7.20 m. While the minimum depth values showed a year-to-year trend towards deepening of the channel, the maximum values' trend was towards shallowing. A comparison of the Chel River channel levels in 2011–2014 indicate, in some places, across the bed, there was a clear tendency towards raising, and in others, to deepening. Local maximum raising of the channel reached 1.20 m during a year, and deepening −0.70 m. The average

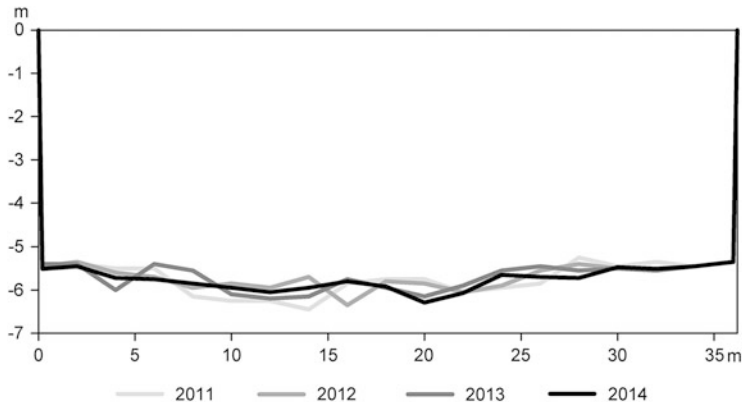

Fig. 5.6 Cross-sections of the Chel riverbed within the Darjeeling Himalaya margin in 2011–2014

course of the channel depth indicates that, the trend towards deepening of about 5 cm year^{-1} in the whole considered period.

The measurements of cross-section located in the mountain part of the Chel River indicate a trend towards deepening of the channel (Fig. 5.6, Table 5.2). The depth of the channel in 2011 ranged from 5.25 to 6.45 m. In 2014, the depth of the bottom of the river was in the range of 5.45–6.30 m. The course of the depth values of the Chel River channel is marked by a year-to-year trend towards deepening the channel in the case of the minimum values and shallowing in the case of the maximum values. Local deepening of the channel during a year reached 0.50 m and shallowing −0.60 m. The course of the average depth of the Chel channel shows a trend towards deepening, up to 1 cm year^{-1}.

5.5 Discussion

The Lish and Gish river beds level in the cross-sections located in the foreland of the Darjeeling Himalayas show their aggradation 3 cm year^{-1} and 0.5 cm year^{-1} respectively in the period 2011–2014. The observed raising of river beds are few orders lower in comparison to previous estimations respectively 11 cm year^{-1} and 9 cm year^{-1} for the period 1982–2004, when several years with extreme floods were noted (Sarkar 2008). This indicates that delivery of the material carried from Himalayas is greater than the volume of the material extracted by human also during years with normal monsoon.

In contrast, the Chel river both in the foreland and in the mountain section of the channel, shows a trend towards incision, reaching an average of 1 cm year^{-1} in the mountains and 5 cm year^{-1} in the foreland. This latter trend can be connected with a massive bed material extraction. According to the information obtained in the field, every day during dry season, in the Chel river, about 3200 t of material are extracted at a 2–3 km section of the river above and below the bridges. The similar trend towards incision the river channel in the foreland of the Darjeeling Himalayas is noticed on the Balason river (a right-bank tributary of the Teesta river), where the volume of extraction has been much greater than the annual river replenishment volume (Tamang and Mandal 2011, 2015). In the mountain part of the Chel river, the rate of channel incision is close to estimated for Siwaliks in central Nepal (Lavé and Avouac 2001).

The presented river beds level changes can be considered as a typical for the period with no particularly extreme rainfall, the consequence of which are catastrophic floods with high geomorphological efficiency. In the years 2011–2014, annual precipitation ranged between 3600 and 4600 mm (data provided by the Upper Phagu Tea Garden, cf. Fig. 5.1). The maximum daily rainfall only once exceeded 200 mm during this period. According to Soja and Starkel (2007), an average annual rainfall in this area ranges from 4000 to 6000 mm but, during some years, it can reach 7000–8000 mm with the daily total up to 800 mm.

Another important factor that should be taken into consideration in analyses of river beds level changes is human activity in the mountain part of catchments. Changes in land use from forested to agricultural use, in headwater areas, are known to increase discharge and sediment supply, which influences downstream channel morphology in complex ways (Liebault and Piegay 2002; Vanacker et al. 2003; Price and Leigh 2006; Wohl 2006). Widespread deforestation started in the Lish, Gish and Chel mountain catchments in the mid-nineteenth century and it is continued to present day, as the result of agriculture, surface coal mining and settlement expansion (Basu and Ghatowar 1988, 1990; Prokop and Sarkar 2012). Land use changes are accompanied by parallel enlargement of the landslides which are the most important factor in generating large surface runoff volumes and coarse sediment delivery during rainfall events (Vanacker et al. 2005; Pike et al. 2010). This is especially visible in the Lish and Gish mountain catchments with large contribution of lithology (Siwaliks molasse, deep weathered Darjeeling gneisses) that is prone to landslides (cf. Fig. 5.1).

The considered cross-sections are located within channel narrowings, at the location of road and rail bridges that, as hydrotechnical structures, influence the course of channel processes. The processes of erosion or accumulation within the channels at the location of bridges may lead to their destruction (Melville and Coleman 2000; Johnson 2006). Incision of the Chel river channel can lead to the exposure of the foundations of the bridges, and thus to washout and the bridge falling during floods. This is particularly dangerous process in alluvial channels. On the other hand, the accumulation of material seen on the Lish and Gish rivers reduces river bed capacity under bridges, and thus increases the likelihood of water overflow during floods over bridges and embankments, as well as their destruction.

5.6 Conclusions

The changes of riverbeds level in the Darjeeling Himalaya and its foreland are influenced by a combination of both natural forces and human activity. Basing on data gathered for the period 2011–2014 with rainfall close to the long-term averages, it can be concluded that:

1. Alluvial beds of the Lish and Gish rivers in the Himalayan foreland tend to have a raising trend. The aggradation of the Lish riverbed (3 cm year^{-1}) is faster, as compared to the Gish riverbed (0.5 cm year^{-1}). Rising of the both riverbed channels is supported by a large contribution of unconsolidated material prone to mass movements as well as intensive human activity related to deforestation for agriculture and surface coal quarry in their mountain catchments.
2. Several order lower rates of aggradation in Lish and Gish rivers in the period 2011–2014 in comparison to previous long term estimations can indicate a dominant role of extreme rainfall and floods with high geomorphological efficiency in sediment delivery to the Himalayan foreland.
3. Both in the Himalayan Chel rocky channel, and in the foreland Chel alluvial channel, there is a tendency to the bed incision. In the mountain section of the river, this process reaches an average of 1 cm year^{-1} and is due to the natural trend of mountain rivers towards incising, while in the foreland (approx. 5 cm year^{-1}) it can be related to the mass extraction of river material by human. Lowering of the riverbeds is supported by low contribution of unconsolidated material that is reflected in small area of landslides in the land use system in the mountain catchment of the Chel River.
4. The estimated scale and direction of the changes in the analyzed riverbeds may be affected by the presence of road and rail bridges as hydrotechnical structures that interfere with the course of channel processes. This issue needs further investigation.

The presented results of riverbeds level changes are of great importance in the context of possible catastrophic floods in the foreland of the Darjeeling Himalaya. Detailed geomorphological consequences of such events, important for the operation of road and rail bridges, can be determined only through long-term measurements, aimed at capturing the greatest number of extreme hydrological events.

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Chapter 6
Bioclimate of the Andaman Islands and Its Impact on the Lives of the Native and Non-native Populations of the Archipelago

Maciej Kędzierski and Dominik Gargol

Abstract The paper discusses the characteristics of the bioclimate of the Andaman Islands using bioclimate indicators such as the universal thermal climate index (UTCI), equivalent temperature (Te), and a physiological indicator – the heart rate (HR). The research was based on daily data obtained from the meteorological station in Port Blair for the period 2005–2012. The period from March to May is the most unfavorable time in the Andaman Islands from the point of view of bioclimatology. The most mild weather conditions exist in July and August; however, these are months with very high precipitation. Climate conditions on the Andaman Islands were determined to be rather unfavorable to the non-native population.

Keywords Negrito people • Bioclimate indicators • Climate determinism • Andaman Islands

6.1 Introduction

The Andaman Islands are an archipelago that is a unique place in many ways. The archipelago remained a "terra incognita" to researchers for many years mainly thanks to its geographic isolation. Additionally, the first historical sources mentioning the islands created a certain mystique about the place. A vast richness of flora and fauna serves as an inexhaustible territory for scientific research. The archipelago's coral reefs and beaches are among the most beautiful in the world and attract multitudes of tourists every year.

However, these are not the most important reasons why the islands should be protected by law and supervised by international organizations. What makes the islands so distinct is the presence of the "Negritos", their native people. There is no other such place in the world, where it would be so easy to conduct archeological

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research on tribal populations using experimental methods. In this part of the world, both archeologists and anthropologists may “transfer themselves” to the world of the Upper Paleolithic. Gaining an in-depth knowledge of the history of the Andamanese natives will allow making the next step in the direction of attaining an understanding of the anthropogenesis of modern man. Bioclimate research may prove to be extremely helpful in this matter, as the bioclimate influences not only the cultural evolution of society, but it also has an effect on the evolution of human DNA (Sun et al. 2007). The indigenous population is systematically decreasing in size. The exogenous population, which consists primarily of immigrants from “nearby” India, is gradually pushing the natives out of their traditional territories. This is why as much attention as possible should be devoted to this fascinating place.

The main aim of this study is to characterize the bioclimate conditions of the Andaman Islands. The impact of climate on native and non-native populations is analysed.

6.2 Materials and Methods

6.2.1 Study Area

The Andaman Islands are located in the Indian Ocean between the Andaman Sea to the east and the Bay of Bengal to the west (Fig. 6.1). The archipelago extends from 10°30′ to 13°41′ North latitude and 92°12′ to 93°57′ East longitude (Davidar et al. 2001). The Andaman and Nicobar Islands are a Union Territory of India. Port Blair is the capital and largest city of the territory. The Coco Islands, which belong to Burma, are also a part of the archipelago from a geographic point of view.

The number of islands that make up the archipelago is difficult to determine due to differences in the understanding of the term “island”. The definition of “island” is imprecise. Many researchers such as Verill (1922), Gourou (1973), Bonniol (1987), Nunn (1994), and Jędrusik (2011) attempted to formulate a definition of “island”. However, none of the proposed definitions have proved to be universal. George Webber (2013), one of the founders and chairman of an organization called the “Andaman Association”, which conducts comprehensive research across the archipelago with an emphasis on its native population, specifies more than 200 islands in the Andaman chain.

More detailed analyses allow specifying a more accurate number of islands in the archipelago, which is 325. The total area of all these islands is 6408 km^2. Just five islands are larger than 100 km^2. Only 26 islands are permanently inhabited. The land area of the archipelago, together with the Nicobar Islands, is 8249 km^2 (Planning Commission of Government of India 2008). The two groups of islands are separated by the Ten Degree Channel, which connects the Indian Ocean and the Andaman Sea. The channel is 140 km wide. This sea barrier geographically

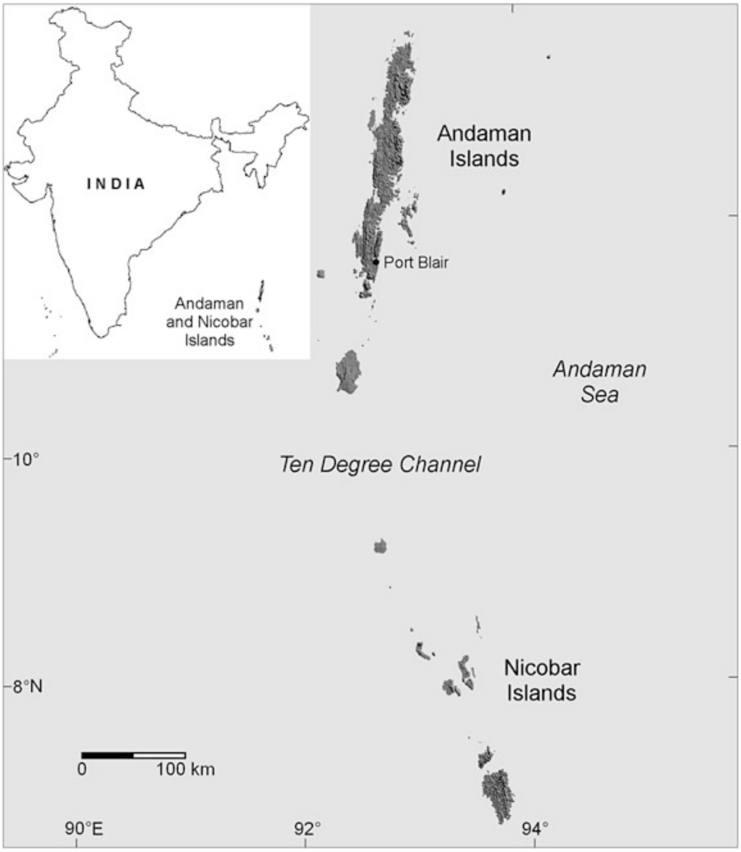

Fig. 6.1 Location of the Andaman Islands

separates the Andaman Islands from the Nicobar Islands, but most of all it prevents cultural diffusion and the mixing of genetic material of local populations (Bera 2002). Port Blair lies at a distance of 1255 km from Kolkata (Calcutta), 1190 km from Chennai, and 1200 km from the city of Visakhapatnam.

The flora and fauna of the two groups of islands has also remained different to a large extent. The Andaman Islands are part of the Indomalaya ecozone, according to the discipline of zoogeography. It must be noted that due to the large distance from the continent (Fig. 6.1), the fauna and flora of these islands are characterized by a large share of endemic species: 60 % of mammals and 40 % of birds are endemic (Government of India Planning Commission 2007). The general area lies within the realm of Hindu civilization (Huntington 1993).

The Andaman Islands are located in the tropical monsoon climate Am, according to the Koppen-Geiger classification. Northeasterly monsoon winds and southwesterly monsoon winds bring heavy rainfall to the Andaman Islands. The mean annual air temperature is 26.2 °C and the mean annual rainfall reach 2870 mm.

The climate is slightly different in different parts of the archipelago, as it stretches over a large distance along a north–south axis. The meteorological station in the islands is located in Port Blair, and the climate of the islands is determined based on data gathered there.

6.2.2 Methods

Data from the meteorological station in Port Blair were obtained from two internet sites: www.meteo.infospace.ru and www.tutiempo.net. The data cover an 8 year period: 2005–2012. The station is located at an elevation of 65 m above sea level. Three bioclimate indicators were used in the study: universal thermal climate index (UTCI), equivalent temperature (Te) and heart rate index (HR).

The UTCI is based on an analysis of heat balance in the human body, performed using the multi-node model of heat exchange (Fiala et al. 2012). Index is defined as the equivalent temperature of air, at which, under reference conditions, the basic physiological parameters of the human body assume the same values as under real conditions.

The UTCI has many applications. Weather alerts and warnings are issued based on the index (heat stress, cold stress) by appropriate weather service organizations. Moreover, it is quite useful in research on climate and bioclimate – assessment of bioclimate, bioclimate mapping, climate interactions, recreation, tourism, climatotherapy, epidemiology, as well as urban planning.

$$\mathrm{UTCI} = f(\mathrm{Ta},\ \mathrm{vp},\ \mathrm{va},\ \mathrm{dTmr\,t}) \tag{6.1}$$

where Ta is air temperature (°C), vp is water vapor pressure (hPa), va is wind velocity at an altitude of 10 m above the ground level, and dTmr t is difference between the mean radiant temperature and air temperature (°C).

The UTCI is based on objective changes in the physiological parameters of the human body occurring under the influence of environmental conditions (Błażejczyk et al. 2013, Table 6.1). This is, undoubtedly, the main advantage of this indicator, as most earlier bioclimate research was based on the subjective sensations of the studied populations.

Values of the UTCI in the study period (2005–2012) were ascribed to levels of heat stress according to a heat stress scale (Błażejczyk et al. 2013). In order to make the analysis easier, heat stress levels that did not have corresponding UTCI values in the study area were omitted; including: very strong cold stress, strong cold stress, moderate cold stress, mild cold stress. These are stress levels that correspond to UTCI values below 9 °C. Extreme heat stress (> +46 °C) is also absent in the study area.

Table 6.1 Assessment scale (UTCI) of the level of heat stress on the human body (Błażejczyk et al. 2013)

UTCI (°C)	Heat stress category	Possible ways of protection
> +46	Extreme heat stress	Temporary body cooling is periodically necessary. Drinking >0.5 l h^{-1} of fluid is necessary. Avoid physical activity
+38–+46	Very strong heat stress	Temporary use of air-conditioned rooms or staying in shaded places is periodically necessary. Drinking >0.5 l h^{-1} is necessary. Reduce physical activity
+32–+38	Strong heat stress	Drinking >0.35 l h^{-1} is necessary. Staying in shaded places is recommended. Periodically, a reduction in physical activity is recommended
+26–+32	Moderate heat stress	Drinking >0.35 l h^{-1} of fluids is necessary
+9–+26	No thermal stress	Physiological thermoregulation is sufficient to maintain thermal comfort
0–+9	Mild cold stress	Use gloves and hat
−13–0	Moderate cold stress	Intensify physical activity and protect face and extremities against cooling
−27 – −13	Strong cold stress	Intensify activity and protect face and extremities against cooling. Wear warmer clothing
−40 – −27	Very strong cold stress	Intensify activity and protect face and extremities against cooling. Use of warmer clothing, providing good thermal insulation, is necessary. Limit outdoor exposure time
< −40	Extreme cold stress	Limit outdoor exposure time to a necessary minimum. Generally, stay at home. If outdoor exposure is required, the use of heavy, thermal insulated and wind-protective clothing is necessary

Equivalent temperature was calculated in order to determine the effect of humidity. It should be understood as the temperature of a unit of air, which would be reached, if at a constant pressure the water vapor contained in that unit of air became condensed, and the latent heat of evaporation released in the process was used to heat up the dry air.

$$\mathrm{Te} = \mathrm{t} + 1.5\mathrm{e} \tag{6.2}$$

where t is air temperature (°C), and e is water vapor pressure (hPa).

Heart rate index is a very simple physiological indicator expressing the heart pulse as the number heart beats per minute (Mroczka 1992).

$$\mathrm{HR} = 22.4 + 0.18\mathrm{M} + 0.25(5\mathrm{t} + 2.66\mathrm{e}) \tag{6.3}$$

where M is metabolic rate (W m^{-2}), t is air temperature, and e is water vapor pressure.

Bioclimate indicators were calculated using BioKlima v. 2.6 freeware software (http://www.igipz.pan.pl/Bioklima-zgik.html). The usefulness of the UTCI and an outline of the effect of the bioclimate on human populations characterized by different anthropometric parameters were based on intuitive methods as well as detailed research on the subject matter.

6.3 Results

6.3.1 Frequency of Occurrence of Heat Stress

In the period 2005–2012, the weather in Port Blair was most frequently associated with strong heat stress, which occurred in 67 % of cases (1945 days out of 2922 studied days). Next, the sensation of moderate heat stress was associated with 17 % of cases, which means it occurred on 497 days. The thermal sensation of very strong heat stress (460 days) was noted 16 % of the studied time. No thermal stress was the least frequent occurrence of cases – only 1 %, i.e. 20 days (Fig. 6.2).

March, April, and August were the only three months in which the sensation of no thermal stress never occurred. All possible levels of heat stress were observed during all other months. During all months, except April, the weather was dominated by strong heat stress. Very strong heat stress was the prevalent thermal sensation recorded in April (61.2 %). The sensation of no thermal stress occurred most frequently in September; however, it was present on only 2.9 % of the days of the month. Such days may occur sporadically in the remaining months; in February, July, November, and December, the sensation occurred only once in the study period.

Moderate heat stress most often occurred in July (33.9 %), August (37.9 %), and September (33.7 %). It occurred the least frequently in February (2.7 %), March (2.8 %), and April (2.9 %). Strong heat stress was noted in January on 89.5 % of days. A second month with such a high share of recorded strong heat stress was December (86.3 %). Strong heat stress occurred the least frequently in April; however, its occurrence frequency reached 36.7 %. The most unfriendly very strong heat stress, was common from February through May reaching a frequency of 21.7 % and 20.2 %, respectively, and in March and April, when it was noted on 41.5 % and 61.2 % of days, respectively (Fig. 6.3).

The heat stress on the human body, experienced in Port Blair over the course of a year, intensifies at the end of the winter monsoon season, which is marked with an increase in the heat stress level (Fig. 6.4). The summer monsoon begins over the Bay of Bengal in April, while the winter monsoon starts in October (Clift and Plumb 2008).

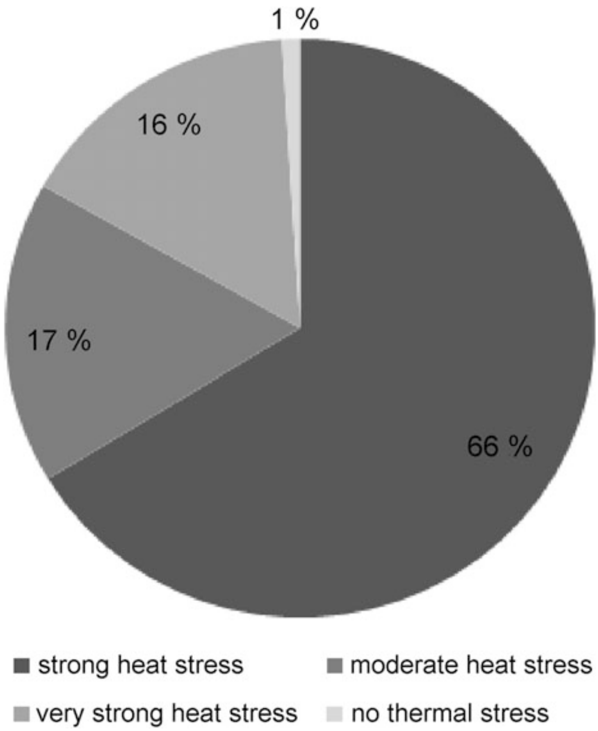

Fig. 6.2 Frequency of occurrence of selected levels of heat stress (%) in Port Blair in the period 2005–2012

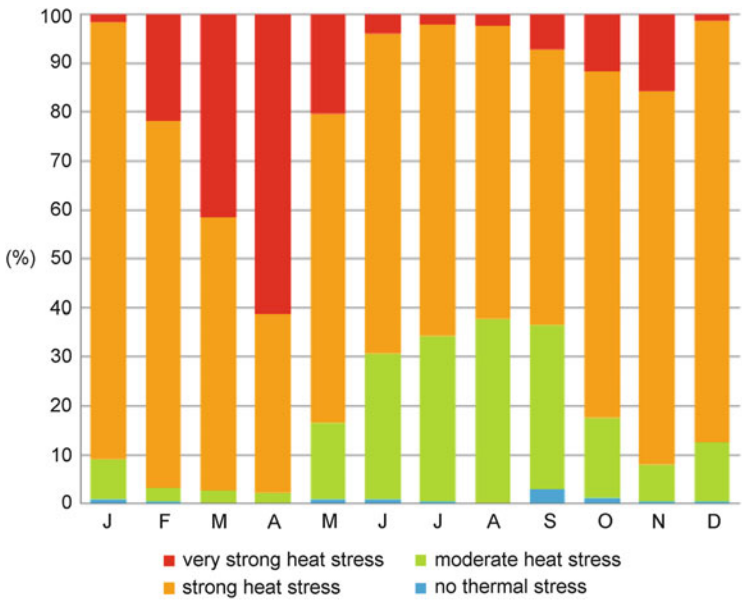

Fig. 6.3 Average monthly frequency (%) of occurrence of selected heat stress levels

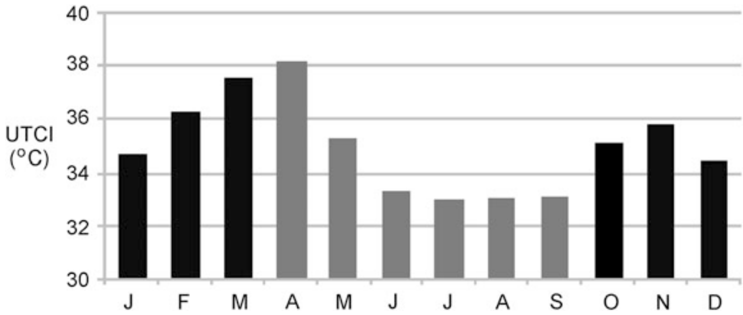

Fig. 6.4 Average value of the UTCI index each month in Port Blair for the period 2005–2012 (summer monsoon season is marked in *gray*)

6.3.2 Assessment of Bioclimate Conditions Based on Air Humidity

The process of emission of heat from the human body is disturbed by air humidity that can be either too low or too high. The sensation of air humidity, in addition to actual water vapor content, also depends on air temperature. At air temperatures above 12 °C, an increase in air humidity intensifies the sensation of heat, while below this air temperature, it intensifies the sensation of cold (Kozłowska-Szczęsna et al. 1997). A steady presence of warm and humid air, a kind of air stagnation, which is exactly what takes place over the Andaman Islands, creates conditions for "oppressive" heat characterized by high humidity or "sweltering" conditions, which makes proper thermoregulation of the human body difficult. The scale of values of the equivalent temperature consists of six types of sensations (Table 6.2).

Only two types of thermal sensation occurred during the study period in the years 2005–2012 (total of 2922 days): 'slightly humid' and 'humid and hot'. The thermal sensation described as 'slightly humid' occurred only 12 times.

6.3.3 The Heart Rate Index

The normal heart rate of a healthy adult person at rest is 70–72 beats per minute (bpm) for men and 78–82 bpm for women (Kozłowska-Szczęsna et al. 1997). The values of the heart rate index (Eq. 6.3) were above 91 bpm, which is a warning rate, everyday during the study period (2005–2012; 2922 days). The maximum value of the heart rate index reached about 115 bpm and its average value was 103 bpm.

Table 6.2 Equivalent temperature scale (Kozłowska-Szczęsna et al. 1997, Eq. 6.2)

Te (°C)	Thermal sensation
<18	Cold
18–24	Cool
24–32	Slightly cool
32–44	Comfortable
44–56	Slightly humid
>56	Humid and hot

6.3.4 *Summary of Bioclimate Conditions*

It is fairly obvious to every person whose work or interests include broadly understood geographic problems and subject matter that living in locations at low latitudes implies the fact that thermal discomfort may be substantial. Information on the difficulties of life in the tropical monsoon climate comes from many sources. Information is available in the form of films, travel books, and news broadcasts on television. There are also other sources, which include the subjective sensation felt while visiting places in the monsoon climate and scientific works on climatology that usually contain only the facts expressed in the form of statistics referring to the progression of basic parameters describing the climate, which do not relate to the physiological and psychological reactions of human subjects.

An advection of tropical air masses may be experienced at middle latitudes. Within several days of such an event, the residents of a given geographic area in the temperate climate may experience an increase in the heart rate and respiratory rate, along with a decrease in blood pressure, increase in body temperature, increased sweating, vasodilation (widening of blood vessels) in the skin, decrease in the hemoglobin index, lowering of the number of leukocytes, as well as less frequent urination and an increased metabolic rate (Tyczka and Ponikowska 1978). The indicators that were developed in this case show how unfavorable the local climate is to human existence. People who reside in the Port Blair area are exposed to heat stress the whole year, which creates a burden on the human body, which results in lowered general physical and mental fitness. Even light physical work is a large burden on the human body.

Above temperatures of 28–30 °C, the evaporation of sweat becomes the last and irreplaceable mechanism of heat loss, which helps maintain thermal homeostasis (Mroczka 1992). However, the daily sensation of oppressive heat makes normal sweating impossible and may lead to the overheating of the human body, and in further consequence, to an array of other serious health complications. Staying in the Andaman Islands involves an increased stress on the circulatory system.

A substantially faster pulse is an apparent symptom of that, among other effects. Traveling to the Andaman Islands is not recommended for certain groups of people, especially for people suffering from circulatory and respiratory illnesses, the elderly, obese people, and any persons with disorders of the thermo-regulatory center of the brain. It is recommended for people staying there to limit physical activity, drink plenty of fluids frequently, and stay in shaded places. The period from March to May is the most unfavorable time in the Andaman Islands from the point of view of bioclimatology. The most mild weather conditions exist in July and August; however, these are months with very high precipitation.

When planning to travel to the Andaman Islands, one must make a choice between a period with relatively low precipitation and very high temperatures and a cooler period with plenty of rainfall.

6.4 Discussion and Conclusions

6.4.1 Tribal Societies in the Andaman Islands and Local Bioclimate

The Andaman Islands were inhabited exclusively by local natives known as Negritos until the second half of the eighteenth century (Radcliffe-Brown 1922, Fig. 6.5). Yet it is difficult to determine the beginnings of human existence in the archipelago due to a lack of archeological material, which could be dated by the radiocarbon method.

It is known for certain that modern man settled the Sahul continent at least 60,000 years ago. This is attested to by the fact that there is a very well examined archeological material that serves as evidence of that. This migration probably took place along the southern coastal areas of Asia. However, there is no proof in the form of genetic testing that would confirm theories that the Andamanese were a group that had separated from the migrating human population and settled the archipelago (Herrnstadt et al. 2003). If this hypothesis is correct, then the presence

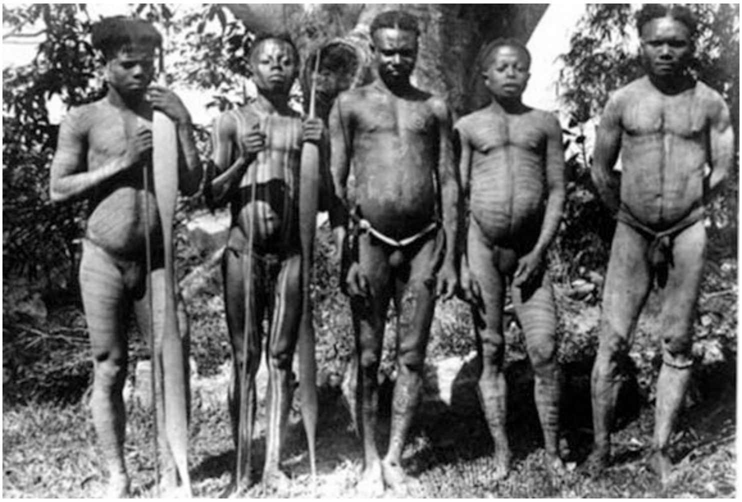

Fig. 6.5 Negrito natives of the Andaman Islands (Llangovan 2010)

of Negritos in the Andaman Islands should be dated at about 70,000 years ago. Research on the genetic background of the Andamanese natives allowed tracing their genetic history reaching as far back as 60,000 years ago. Nevertheless, this does not mean that they inhabited the archipelago at the time; perhaps they had settled the continental part of Asia (Dennell and Petraglia 2012).

It is important, from the point of view of bioclimatology, to determine the date when the archipelago was settled. This would help to determine the rate and the changes caused by evolutionary adaptation of the local population to climate conditions. The conditions at this geographic latitude could not undergo great changes in the past, with the exception of the volcanic winter caused by the eruption of the Toba Volcano in Sumatra, which occurred some 73,000 years ago (Gathorne-Hardy and Harcourt-Smith 2003).

It seems that the presence of modern *Homo sapiens* in this region was unlikely at a time so remote in the past. It is estimated that during the last glacial maximum, the temperature in Indonesia was lower than it is today, on average, by 2–4 °C (Mannion 1991). Similarly, this must have been the situation in the Andaman Islands as well. However, the anthropometric parameters of the Andamanese natives substantially differ from the average for the human population in general (Table 6.3, Fig. 6.6).

A comparison of the physiological parameters of Negritos and those of the world population undoubtedly indicates that adaptation changes have taken place, which express themselves in the form of increased average body temperature, faster pulse, and higher breathing frequency (Table 6.4).

The most noticeable features of Negritos are their small stature and very dark color of skin. Their skin color is so dark that in some cases it takes on a bluish tinge. Anthropologists are still engaged in a debate on exactly why Negritos are unusually short. The most common hypothesis states that the short stature of Negrito natives may treated as a form of adaptation to the natural environment (Diamond 1992; Perry and Dominy 2009). Other hypotheses express views that oppose such direct geographic determinism. These argue that an additional evolutionary predisposition to achieve sexual maturity and reproduce at an earlier age is the cause, which is to be a result of a short average lifespan (Migliano et al. 2007).

Perhaps the short stature of Negrito natives is a result of specific allopartic speciation that revealed itself not in the emergence of a new species, but in visible changes in anthropometric parameters. Negritos inhabit areas where heat stress is certainly experienced most of the year. Heat stress may also be a cause of their short stature. Attempts to find a scientific answer to the question of the cause of shortness in people in different societies appear to be based on assumptions that are too general as well as on an erroneous search for a universal theory, which would fit all investigated cases.

A detailed anthropological analysis of all Negrito societies and other societies characterized by short stature should be performed. There may be as many answers as the number of short person communities. This is rather not an example of convergent evolution that might have resulted from facing the problem of a short

Table 6.3 Average values of anthropometric parameters of the adult Andamanese natives of the Jarawa tribe (Sarkar and Sahani 2002)

Parameter	Men	Women
Height (cm)	152.10	141.34
Weight (kg)	45.78	39.75
Body mass index (kg m^{-2})	19.6	19.7

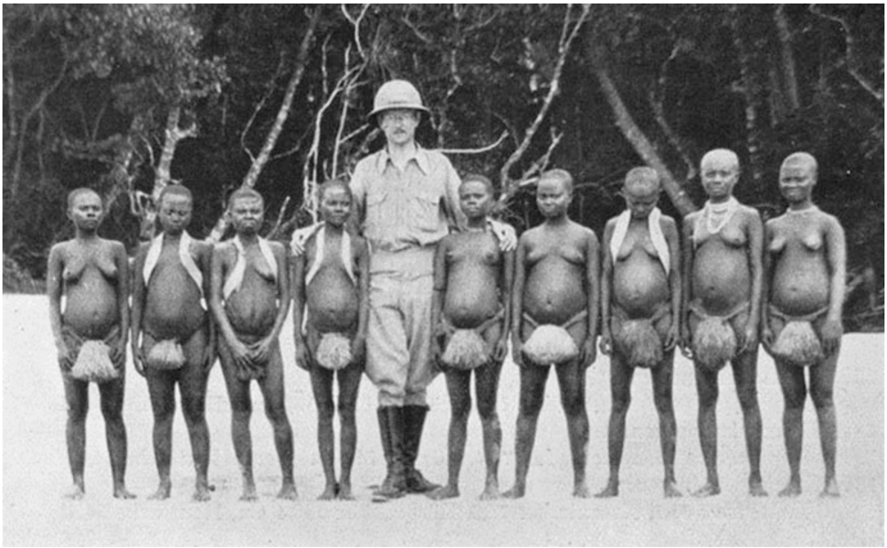

Fig. 6.6 Adult women of the Andaman Archipelago (Brower 2009)

Table 6.4 Selected physiological parameters of Negritos of the Andaman Islands (Webber 2013)

Group	Body temperature (°C)	Pulse (number min^{-1})	Breathing frequency (respiratory rate) (breaths min^{-1})
Negritos of the Andaman Islands			
Men	>37.2	82	19
Women	>37.5	93	16
General world population			
Men	<37.0	70–72	16
Women	<37.0	78–82	16

and dangerous life. The problem surely results from the characteristics of the local bioclimate, if not directly, then indirectly.

The Andamanese people did not build an advanced civilization due to the lack of a stimulus in the form of substantial change in local climate conditions. To the contrary, an unfavorable and persistent bioclimate made working hard impossible, and it may also be a cause of their short stature. Additionally, the local natives did not maintain any contact with other societies over the millennia, which made exchange of technology and development of trade impossible. Today, many researchers consider these key factors to be the basis for the development of first human civilizations. The local bioclimate also greatly influenced the process of colonization of the archipelago by Europeans. In 1796 the colony located at the site of today's Port Cornwallis was abandoned due to poor conditions, considered unsuitable for living. The Andaman Islands became once again free of colonists for a period of 60 years (Radcliffe-Brown 1922).

6.4.2 Universality of the UTCI

The UTCI is based on the multi-node model of heat exchange. This model relies on the physical parameters of an average person, whose weight is 73.5 kg, and who has 14 % fat tissue and whose surface area of skin is 1.86 m^2 (Fiala et al. 2012). It is, therefore, apparent that the basic parameters, which serve as a basis for the calculation of UTCI values, do not fit the Andamanese natives or many other societies. The surface area of the skin itself causes large differences in heat exchange (Frisancho 1993).

The Fiala model consists of two sub-systems of heat exchange: (1) an active sub-system, (2) a passive sub-system. The passive sub-system explains heat transfer within 19 different body parts, with each part still divided into five layers (bone, muscle, fat tissue, subcutaneous tissue, skin) and two or three segments (anterior, posterior, interior). A single body part with a layer and a segment form what is called a node. The algorithms utilized in the Fiala model describe heat transfer through more than 300 nodes (Błażejczyk et al. 2013). A method that is this complex, thinking logically, cannot be accurate and suitable if the model's assumptions differ so substantially from the actual characteristics of each studied community.

The second sub-system controls the physiological mechanisms of thermoregulation. Some communities have evolved unique mechanisms. Isolation hypothermia is an example of such an evolutionary development. In an average European remaining at rest and deprived of clothing, a temperature below 26–28 °C (Klonowicz and Kozłowski 1970) will cause, following a certain amount of time, an increase in the metabolic rate in order to increase the production of internal body heat. Australian Aborigines and Bushmen of the Kalahari spend nights without covering their bodies.

It is under these circumstances that their bodies cool down by several degrees, but with no metabolic reactions, which causes decreased heat loss (Trojan 1985). Andamanese natives also do not cover their bodies and do not make clothes (Radcliffe-Brown 1922). It is known that not only the Andamanese, but also many other representative tribal peoples differ from the general population. The features that are different include body temperature, heart rate at rest, amount of excreted sweat, number of sweat glands, and skin color. Their physiological reactions to a change in UTCI value will be different than those of the general population for the reasons related to the differences.

The UTCI is currently the best tool to assess bioclimate conditions. However, the sub-systems that the Fiala model is based on make the model not appropriate to be used in the case of populations whose parameters "diverge" from averages for the general population. As a result of this, the UTCI is not a tool that can be useful in studies on many societies. To a geographer, these are fascinating groups of individuals whose uniqueness requires more detailed studies and a search for new solutions to old problems related to the effect of the bioclimate on distinctive populations.

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Chapter 7
Spatial and Temporal Variations of Rainfall in the Southern Part of the Meghalaya Plateau

Dominik Gargol and Roman Soja

Abstract Southern part of the Meghalaya Plateau is commonly known as a place with the highest annual rainfall in the world. The analysis of rainfall variability was carried out using data collected from tippet-bucket SEBA RG50 rain gauges which were located in Cherrapunji, Mawsynram and Pynursla between March and October of 2005. Annual rainfall totals in Mawsynram and Cherrapunjee were over 2000 mm higher than in Pynursla located 20 km east, closer to the interior of plateau. Increase of annual rainfall from east to west suggests that even higher rainfall amounts may be expected in areas west of Mawsynram – in the southern part of the Meghalaya Plateau. The analysis also shows that rainfall intensity was the highest in June and during the pre-monsoon season at all three sites. The diurnal rainfall pattern follows a distinct variation of peak rainfall at nighttime and minimum hourly rainfall between 15:00 and 20:00.

Keywords Extreme rainfall • Rainfall intensity • Rainfall duration • Meghalaya Plateau

7.1 Introduction

The southern part of the Meghalaya Plateau is a region characterized by some of the highest annual rainfall in the world (Rakhecha and Clark 1999; World Meteorological Organization 2008; Soja 2003). The primary reasons for this include the plateau's location within the range of monsoons (Rakhecha and Singh 2009), intra-seasonal oscillations, as well as elevation favouring a lifting of the southerly flow over the steep southern side of the plateau (Pathan 1994; Beresford and O'Hare 1999; Kataoka and Satomura 2005; Hoyos and Webster 2007; Murata et al. 2007, 2008; Romatschke and Houze 2011; Houze 2012; Goswami 2012; Sato 2013). Thus macroscale meteorological conditions in the study area are strongly affected by

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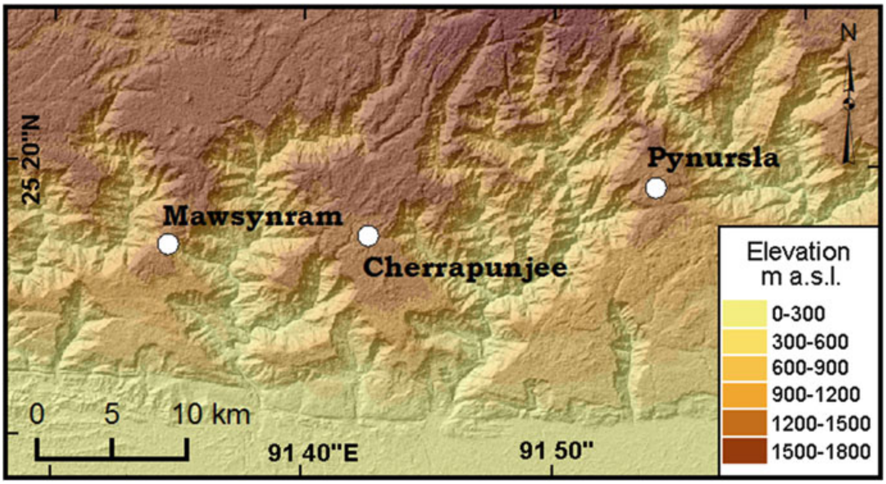

Fig. 7.1 Relief in the southern part of the Meghalaya Plateau. *White* dots indicate rain gauge location

mesoscale and microscale conditions associated with highly variable local relief. Consequently, the purpose of this paper is to discuss variances in the spatial and temporal distribution of rainfall at three sites – Cherrapunjee, Mawsynram, and Pynursla, located on the southern slopes of the Meghalaya Plateau (Fig. 7.1).

7.2 Methods

The paper is based on rainfall amount and duration data collected for monthly, daily, and hourly time intervals from March to October of 2005. Period from March to May was defined as a pre-monsoon season (Murata et al. 2008), June to August as a monsoon season (Fujinami et al. 2014; Beresford and O'Hare 1999; Kamal-Heikman et al. 2007) and September and October as a post-monsoon season The data were collected by R. Soja as part of a Polish-Indian collaboration project – Institute of Geography and Spatial Organization Polish Academy of Sciences and Department of Science and Technology in New Delhi and North Eastern Hill University in Shillong (Meghalaya). The data were obtained using a SEBA RG-50 rain gauge featuring a digital data logger. The precision level of the gauge was 0.1 mm and its temporal resolution was 1 s. The rainfall event was defined as rainfall that was separated by rainfall break lasting at least 12 min, as the SEBA producer suggests. The two events define this to be a one rainfall period. Rain gauges were installed at three sites in the southern part of the Meghalaya Plateau: Cherrapunjee (25°15′N, 91°44′E), at an elevation of 1303 m, Mawsynram (25°18′N, 91°35′E), at an elevation of 1401 m, and Pynursla (25°18′N, 91°54′E), at an elevation of 1380 m. Rainfall intensity (mm min^{-1}) was calculated as the ratio of the rainfall amount per rainfall period and duration. Authors used the Indian Standard Time (IST) that is Coordinated Universal Time (UTC) +5.5 h.

7.3 Results

7.3.1 Annual, Seasonal and Monthly Rainfall Totals

The analysis of data collected at three sites between March and October of 2005 indicates the highest amount of rainfall at the Mawsynram (7911.2 mm). The rainfall for the same period at the Cherrapunjee was 7704.5 mm, while at the Pynursla the rainfall was much lower at 5664.6 mm.

The highest monthly rainfall in the pre-monsoon season between March and May (Murata et al. 2008) were recorded at the Cherrapunjee, whereas during the monsoon season and afterward (Beresford and O'Hare 1999; Kamal-Heikman et al. 2007), the highest amounts were recorded at the Mawsynram (Fig. 7.2). The largest difference was noted in August when the rainfall at Mawsynram was 321 mm higher than that at Cherrapunjee and 1032.7 mm higher than that at Pynursla (Fig. 7.2).

7.3.2 Rainfall Duration

Rainfall occurs for about 50 h per month (2 days, i.e. 3–8 % of each month) between March and May. This increases to about 297 h per month (12–13 days, i.e. 35–40 % of each month) during the monsoon season between June and August. The monsoon weakens in September, but rainfall still affects 10 % of the month and then decrease

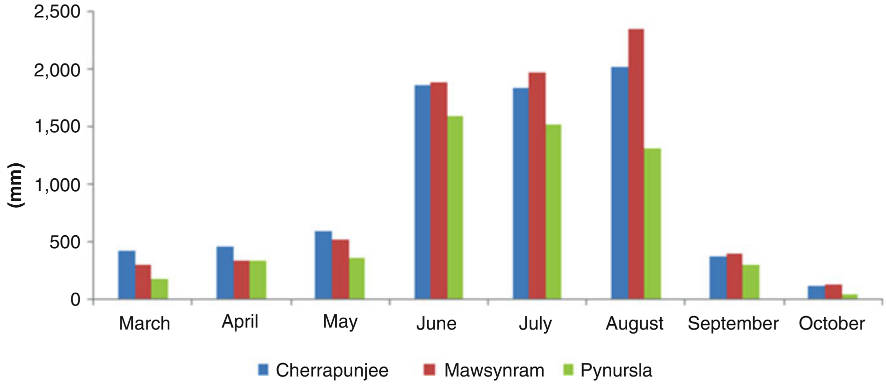

Fig. 7.2 Monthly rainfall (mm) at Cherrapunjee, Mawsynram, and Pynursla between March and October of 2005

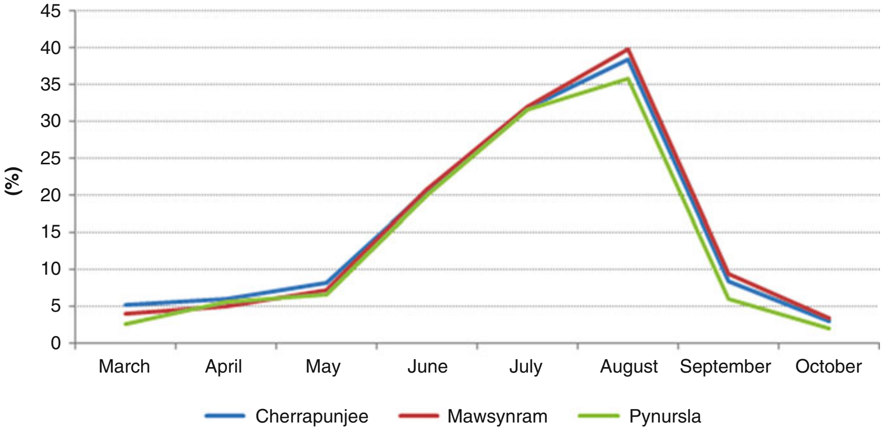

Fig. 7.3 Rainfall duration per month (%) at Cherrapunjee, Mawsynram, and Pynursla between March and October of 2005

to less than 5 % in October (Fig. 7.3). Rainfall duration is virtually the same for all three studied sites for May, June, and July regardless of rainfall total.

7.3.2.1 Days with Rainfall Totals Exceeding 100 mm

A total of 27 days with rainfall exceeding 100 mm were noted in Cherrapunjee between March and October. The corresponding number of days at Mawsynram was 24 and Pynursla 19. The number of days with rainfall exceeding 100 mm for the monsoon season only was 25 for the measurement site at Cherrapunjee, 23 for Mawsynram, and 18 for Pynursla (Table 7.1). The highest rainfall intensity values, daily totals, and hourly totals recorded for days with rainfall exceeding 100 mm were noted in June, while much lower values were noted in late July and early August (Table 7.1).

7.3.2.2 Longest Rainfall Series

The "rainfall series" was defined as a 24-h period and sequences of 24-h periods receiving at least 0.1 mm of rainfall (Twardosz 2007, 2010). In light of this definition, rainfall series for Cherrapunjee and Mawsynram have been identified starting with June 11th and ending with August 28th for both sites. The rainfall series for the Pynursla was identical except for one day without rainfall on July 21st. The mean daily rainfall total for this time period at Mawsynram was 77.2 mm. The corresponding value at Cherrapunjee was 69.7 mm; and 54.2 mm at Pynursla (Fig. 7.4). The series followed a sinusoidal pattern with four periods characterized by very high rainfall totals. The first period lasted from 17th to 24th June with mean

Table 7.1 Days with rainfall exceeding 100 mm in Cherrapunjee, Mawsynram, and Pynursla between June and August of 2005

Cherrapunjee				Mawsynram				Pynursla			
Date	Daily rainfall (mm)	Highest hourly rainfall (mm)	Mean rainfall intensity (mm min^{-1})	Date	Daily rainfall (mm)	Highest hourly rainfall (mm)	Mean rainfall intensity (mm min^{-1})	Date	Daily rainfall (mm)	Highest hourly rainfall (mm)	Mean rainfall intensity (mm min^{-1})
1.06	142.5	56.7	0.53	18.06	264.7	68.5	0.61	1.06	118.3	45.4	0.44
17.06	149.5	49	0.33	19.06	195.4	62.2	0.37	17.06	100	29.5	0.28
18.06	194.5	81.8	0.53	21.06	277.9	81.2	0.5	19.06	129.1	25.3	0.25
19.06	140.2	34.9	0.25	22.06	147	24.7	0.17	20.06	123.9	26.7	0.24
20.06	124.7	28.5	0.22	23.06	339.6	73.2	0.35	21.06	161.6	33.9	0.22
21.06	329.8	103.6	0.54	24.06	110.2	34.6	0.17	22.06	156.5	20.1	0.18
22.06	118.1	25.9	0.16	10.07	130.2	14.4	0.14	23.06	249.4	49	0.24
23.06	177.3	35.2	0.21	12.07	270	30.8	0.22	24.06	169.5	34.1	0.23
24.06	122.5	26.1	0.15	13.07	177.4	32.2	0.2	12.07	173.5	20.4	0.14
10.07	129.1	16.8	0.14	14.07	185.9	33.6	0.23	14.07	122.1	21.7	0.14
12.07	177.5	21.7	0.16	15.07	157.9	14.9	0.13	15.07	195.9	21	0.16
13.07	112.5	21.1	0.14	17.07	101.3	19.9	0.13	19.07	150	23.7	0.15
14.07	136.8	29.1	0.2	18.07	107.9	23.8	0.15	5.08	109.5	13	0.08
15.07	172.4	17.6	0.13	5.08	162.8	24.9	0.13	6.08	120.9	14.3	0.08
18.07	110.6	17.5	0.12	6.08	167.2	17.2	0.13	22.08	106.2	22	0.09
19.07	144.7	18.1	0.17	7.08	123.7	26.6	0.09	23.08	149.2	23.1	0.13
5.08	126.4	12.7	0.1	19.08	101.8	18.5	0.13	24.08	102.4	42.5	0.15

(continued)

Table 7.1 (continued)

Cherrapunjee				Mawsynram				Pynursla			
Date	Daily rainfall (mm)	Highest hourly rainfall (mm)	Mean rainfall intensity (mm min^{-1})	Date	Daily rainfall (mm)	Highest hourly rainfall (mm)	Mean rainfall intensity (mm min^{-1})	Date	Daily rainfall (mm)	Highest hourly rainfall (mm)	Mean rainfall intensity (mm min^{-1})
6.08	125.6	17.7	0.1	20.08	162.6	17.6	0.15	25.08	106.4	16.2	0.13
19.08	104	26.8	0.18	21.08	144.8	27.5	0.13				
20.08	112.2	18.9	0.13	22.08	181.1	21.3	0.17				
21.08	161.3	53.7	0.15	23.08	265.7	38.4	0.21				
22.08	181.5	26	0.15	24.08	116.1	26.5	0.15				
23.08	206.3	26.4	0.16	25.08	247.1	62.5	0.29				
24.08	151.5	36.2	0.17								
25.08	188.3	22	0.2								

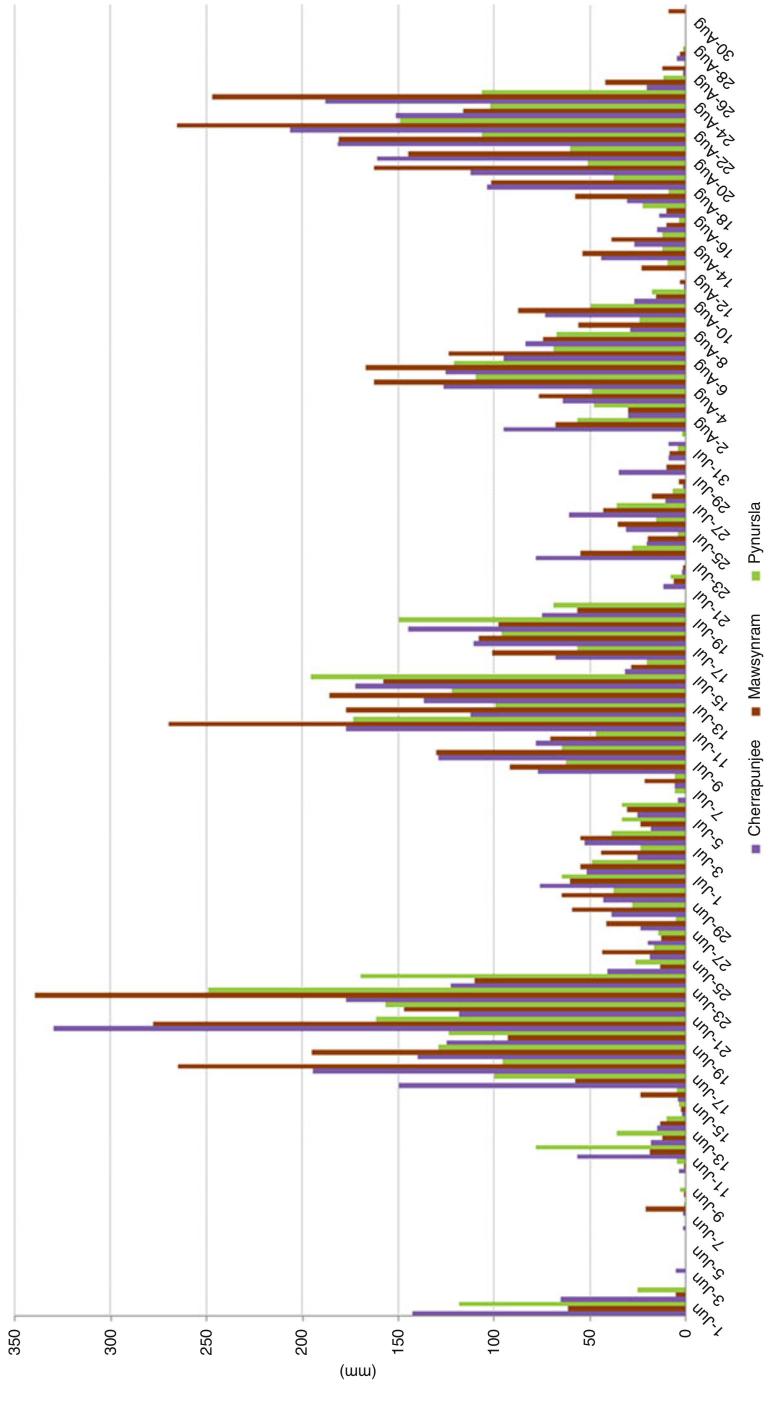

Fig. 7.4 Daily rainfall (mm) in Cherrapunjee, Mawsynram, and Pynursla between June and August of 2005

daily rainfall totals at 185.7 mm at Mawsynram, 169.6 mm at Cherrapunjee, and 148.3 mm at Pynursla. The rainfall totals for the entire first period reached 1485.5, 1356.6, and 1185.9 mm, respectively (Fig. 7.4).

The mean number of hours with rainfall per day fluctuate around 16.5. The last period (fourth period) with high rainfall began on August 19th and lasted until August 25th. The highest mean daily rainfall was noted for Mawsynram at 157.7 mm, followed by Cherrapunjee at 140.7 mm, and Pynursla at 78.1 mm. The rainfall totals for this period were 1261.5, 1125.4, 625.0 mm, respectively (Fig. 7.4). The mean number of hours with rainfall per day was about 15 at both Cherrapunjee and Mawsynram and about 13.5 at Pynursla.

The sinusoidal pattern of high and low rainfall follows the intra-seasonal oscillations (Ohsawa et al. 2001; Sato 2013). Fujinami et al. (2011) was able to show that the monsoon period in Bangladesh (June–August) includes a number of high rainfall periods lasting 7–25 days that alternate with periods with less rainfall. Murata et al. (2008) found moist air moving across the Bay of Bengal in the time prior to strong rainfall periods in the Cherrapunjee area in 2004. These air masses were observed up to 7 km of altitude.

7.3.2.3 Diurnal Rainfall Patterns

7.3.2.3.1 Rainfall Course and Amount

Similar diurnal rainfall cycle is observed at the three analysed rainfall stations between March and October. The evening maximum begins at about 17:00 and lasts until 2:00 or 4:00 depending on the site. This is followed by a decrease in rainfall at all three study sites until 16:00 (Fig. 7.5). The site with the highest rainfall between 6:00 and 15:00 is Mawsynram (except for noon). The largest rainfall between 16:00 and 23:00 is recorded at Cherrapunjee. Both sites receive the highest rainfall via an

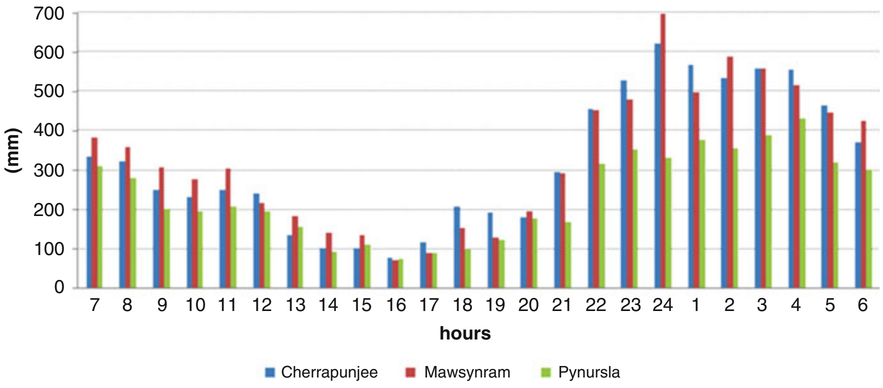

Fig. 7.5 Hourly rainfall totals (mm) for Cherrapunjee, Mawsynram, and Pynursla between March and October of 2005

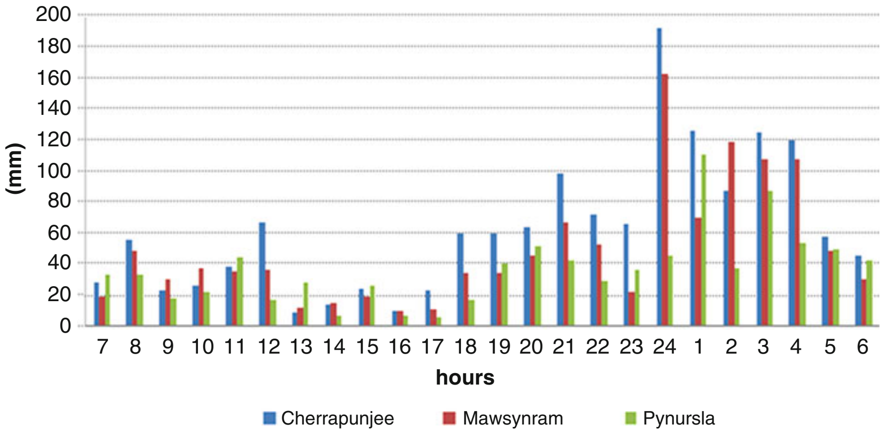

Fig. 7.6 Hourly rainfall totals (mm) for Cherrapunjee, Mawsynram, and Pynursla between March and May of 2005

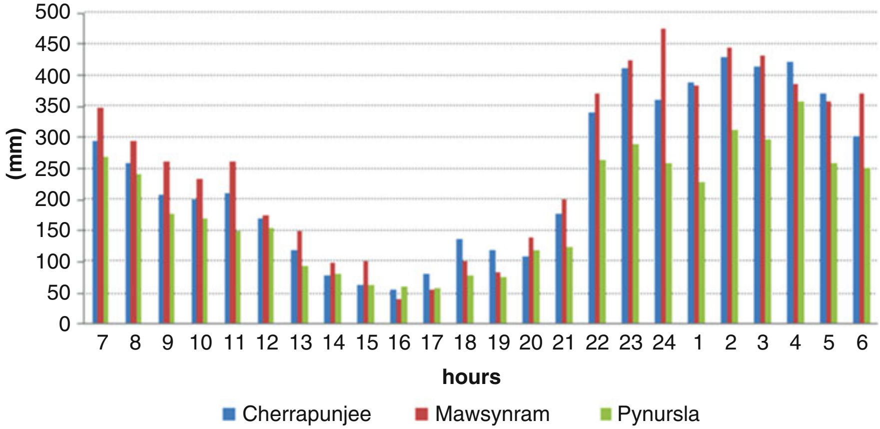

Fig. 7.7 Hourly rainfall totals (mm) for Cherrapunjee, Mawsynram, and Pynursla between June and August of 2005

alternating pattern between midnight and 5:00. In effect, more than half the annual rainfall is noted from 22:00 to 5:00. Similar results were obtained by Das (1951) and Starkel et al. (2002). Observations were also confirmed using geostationary satellite data and meteorological radar. Ohsawa et al. (2001) as well as Romatschke and Houze (2011) has shown that rainfall intensity on the southern slopes of the Meghalaya Plateau is greatest between midnight and 6:00 due to the strongest convection. Kataoka and Satomura (2005) who used a mesoscale model to explain this phenomena, suggest greater instability of the atmosphere at nighttime – in conjunction with stronger southwesterly winds that push humid air over the Meghalaya Plateau.

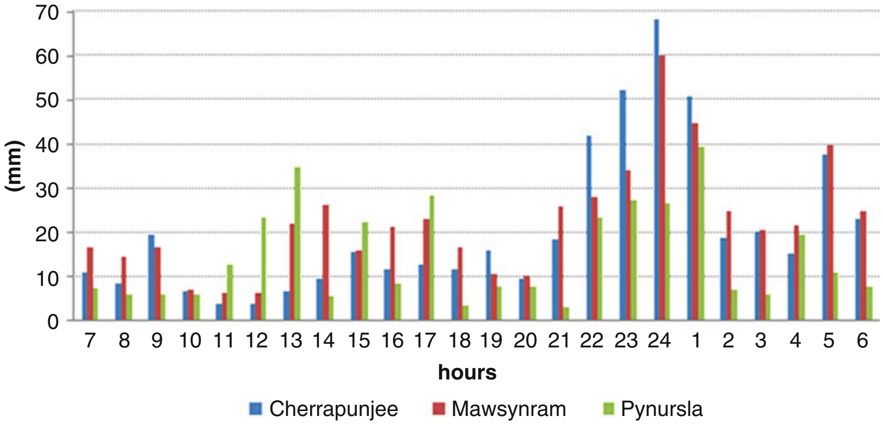

Fig. 7.8 Hourly rainfall totals (mm) for Cherrapunjee, Mawsynram, and Pynursla between September and October of 2005

Hourly rainfall patterns in the pre-monsoon period resemble annual rainfall patterns, although are more variable. A sinusoidal pattern can be observed for each 24-h period (Fig. 7.6). Data from each measurement site show a decrease in rainfall between 8:00 and 10:00 as well as an increase between 11:00 and 12:00. A lowest rainfall can be observed prior to 17:00.

Hourly rainfall totals remain constant between 18:00 and 23:00 with slightly increase around 21:00. Highest diurnal rainfall occurs between 24:00 and 1:00. Relatively strong rainfall lasts until 4:00 (Fig. 7.6). Hourly rainfall totals in the monsoon season are strongly correlated with annual rainfall patterns, which is also linked with the largest share of rainfall in the summer months (June–August). A large decrease in rainfall (200–250 mm) occurs between 7:00 and 17:00. Peak diurnal rainfall is observed between 22:00 and 5:00 (Fig. 7.7). At the Cherrapunjee, a peak is reached around 23:00 and between 2:00 and 3:00. At the Mawsynram, this occurs at midnight and between 2:00 and 3:00. At the Pynursla, rainfall is somewhat lower and its maximum occurs at 4:00 (Fig. 7.7).

Hourly rainfall data for the post-monsoon period show the largest rainfall amounts between 22:00 and 1:00. Rainfall amounts in Pynursla are also noted to be quite high – and exceed rainfall amounts in Mawsynram and Cherrapunjee in the afternoon (Fig. 7.8).

Maximum hourly rainfall values follow a reasonably consistent schedule at both Cherrapunjee and Pynursla. Peak values at the two gauging sites are observed between 23:00 and 6:00 in June, while in the case of the Mawsynram, this occurs mostly in August (Table 7.2). Peak rainfall at 20:00 at all three gauging sites occurs between March and May (Table 7.2).

Table 7.2 Maximum hourly rainfall (mm) for Cherrapunjee, Mawsynram, and Pynursla between March and October of 2005

	Date	Cherrapunjee	Date	Mawsynram	Date	Pynursla
7	19.06	34.9	18.06	68.5	24.06	28.0
8	14.07	25.5	18.06	41.3	24.06	34.1
9	22.08	26.0	23.08	24.8	22.06	20.1
10	23.08	26.4	23.08	36.8	15.07	18.3
11	22.06	21.7	23.08	38.4	18.07	20.2
12	22.06	25.9	22.08	21.3	12.07	20.4
13	11.07	17.9	17.07	19.9	24.09	31.5
14	23.08	12.1	12.07	16.9	06.08	14.3
15	10.05	9.5	23.06	18.3	16.09	9.5
16	23.06	15.5	06.08	7.7	23.06	10.6
17	19.07	15.3	20.09	11.7	24.09	23.6
18	21.08	53.7	13.08	23.0	23.08	15.2
19	30.07	20.1	23.08	10.0	22.08	22.0
20	26.05	18.0	09.04	14.6	28.03	20.7
21	02.08	44.2	02.08	28.3	15.05	18.2
22	24.08	36.2	18.06	50.8	24.08	42.5
23	18.06	81.8	19.06	62.2	01.06	45.4
24	27.05	28.9	25.08	62.5	19.06	25.3
1	20.06	22.3	21.08	44.0	22.09	32.4
2	24.07	69.2	21.08	81.2	23.06	49.0
3	21.06	44.4	23.08	71.2	23.06	47.4
4	21.06	69.6	23.08	73.2	23.06	48.1
5	21.06	103.6	23.08	47.0	24.06	29.3
6	12.06	30.6	18.06	27.4	12.06	31.5

7.3.2.3.2 Rainfall Duration and Intensity

The diurnal course of the rainfall duration in the pre-monsoon season shows maximum at night. Mean rainfall duration between 7:00 and 20:00 ranges between 1 and 4 min, while between 24:00 and 4:00, this range extends from 5 to slightly more than 8 min (Fig. 7.9).

Hourly rainfall duration patterns in June, July, and August follow a clear diurnal cycle at each studied site (Fig. 7.10). Rainfall occurs, on average, for more than 25 min per hour between 24:00 and 6:00. Rainfall duration then decreases between 7:00 and 16:00, which serves as a minimum. The rate of decrease is about 6 min per hour. Rainfall duration then begins to increase slowly until about 18:00, at which point it begins to increase rapidly until 24:00. Hourly rainfall duration patterns closely follow hourly rainfall total patterns, which is shown by a high (positive) coefficient of correlation – 0.93 for each of the three sites.

Rainfall duration in September and October resembles that in the period starting with March and ending with May. However, rainfall duration for the night hours at

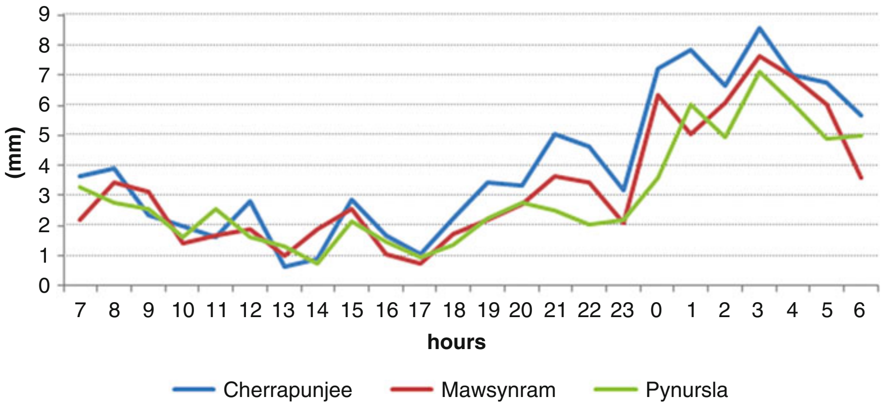

Fig. 7.9 Hourly rainfall duration (min) for Cherrapunjee, Mawsynram, and Pynursla between March and May of 2005

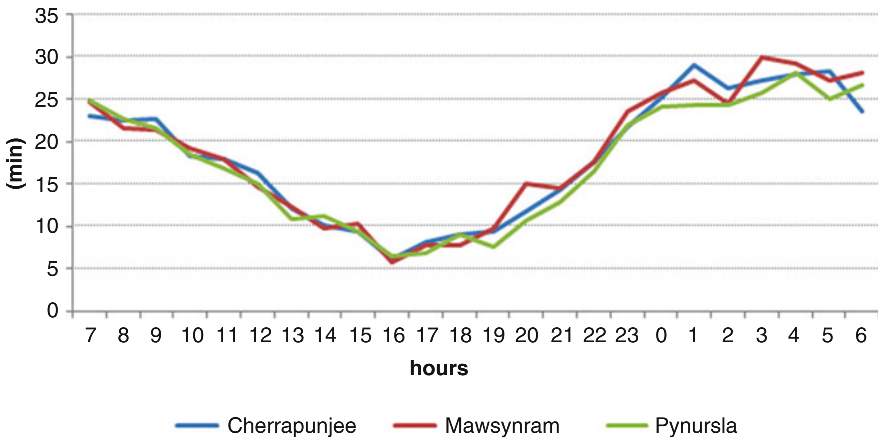

Fig. 7.10 Hourly rainfall duration (min) for Cherrapunjee, Mawsynram, and Pynursla between June and August of 2005

the Mawsynram is slightly greater relative to that noted at the Cherrapunjee (Fig. 7.11).

Mean daily rainfall intensity in the pre-monsoon period varies substantially from one gauging site to another. The Cherrapunjee features two maximums – one at 18:00 and another at 24:00 – both of which exceed 0.27 mm min^{-1}. Maximum intensity at Mawsynram occurs between 10:00 and 11:00. At the Pynursla, the maximum occurs at 14:00, which also serves as a daily minimum for the Mawsynram (Fig. 7.12). Mean rainfall intensity at Cherrapunjee and Mawsynram is the same at 0.16 mm min^{-1}. At the Pynursla, mean rainfall intensity is lower at 0.14 mm min^{-1}.

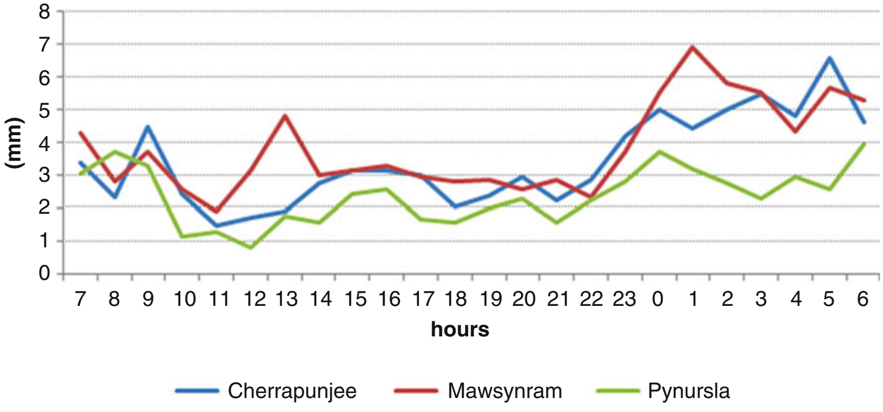

Fig. 7.11 Hourly rainfall duration (min) for Cherrapunjee, Mawsynram, and Pynursla in September and October of 2005

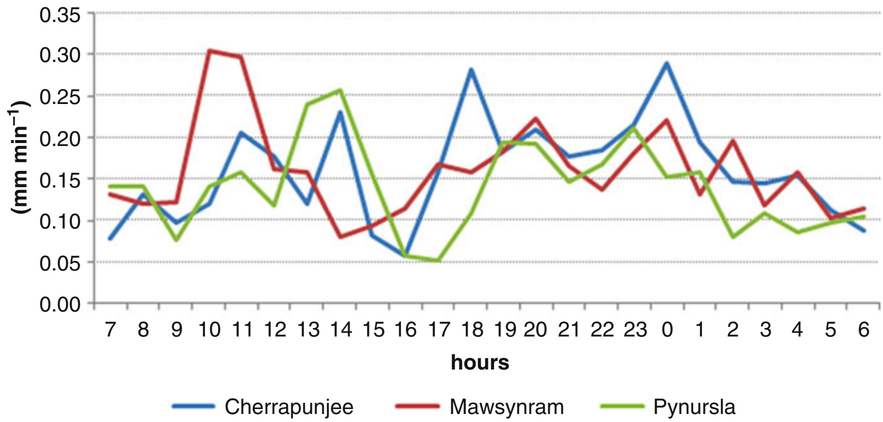

Fig. 7.12 Hourly mean rainfall intensity (mm min^{-1}) for Cherrapunjee, Mawsynram, and Pynursla between March and May of 2005

Hourly mean rainfall intensity varies only somewhat less during the area's monsoon season. The largest fluctuations are observed at Pynursla (0.11–0.57 mm min^{-1}), which also serves as a maximum for all three gauging sites (Fig. 7.13). Relatively high rainfall intensity at around noon are noteworthy as well as those around 17:00. In the former case, this may be due to convective rainfall (Prokop 2007). On the other hand, increased rainfall intensity around midnight may be explained by the diurnal rainfall cycle, which reaches its maximum at this time of day. It is noteworthy that the relatively high intensity noted at 23:00 is accompanied by relatively high rainfall totals and short rainfall duration. The hours that follow are characterized by rainfall totals similar to the total at

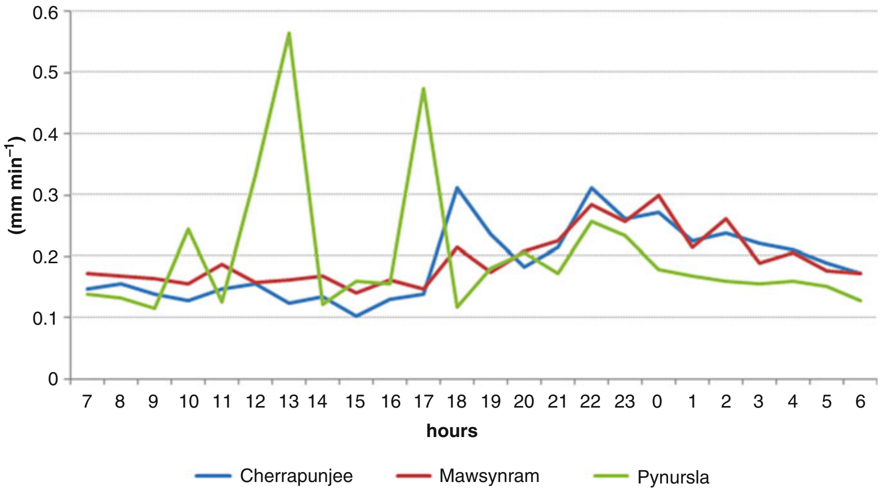

Fig. 7.13 Hourly mean rainfall intensity (mm min^{-1}) for Cherrapunjee, Mawsynram, and Pynursla between June and August of 2005

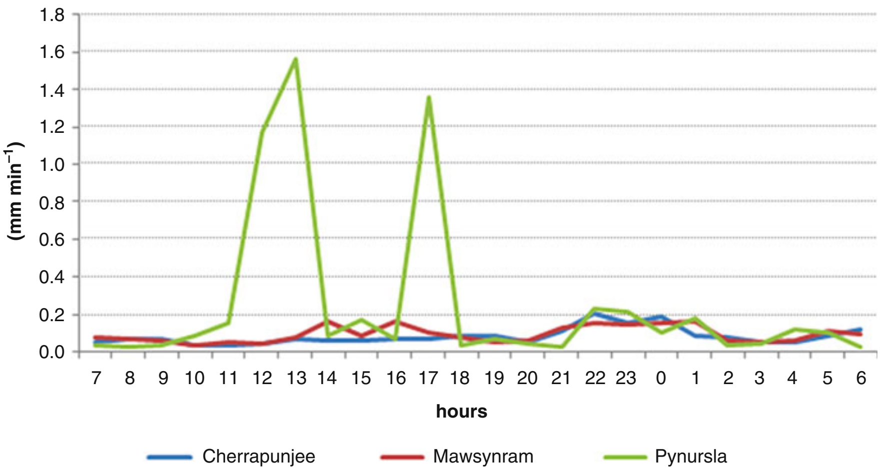

Fig. 7.14 Hourly mean rainfall intensity (mm min^{-1}) for Cherrapunjee, Mawsynram, and Pynursla in September and October for 2005

24:00, but corresponding durations are, on average, longer by 5 min. In effect, high intensity values are of short duration in nature.

Rainfall intensity at Pynursla (more than 1.3 mm min^{-1}) was found to be several times higher than that at Cherrapunjee on several occasions in September and October. Very high rainfall intensity was noted during several extreme events characterized by rainfall of more than 30 mm per 3 min (Fig. 7.14).

Table 7.3 Maximum rainfall (mm) for Cherrapunjee, Mawsynram, and Pynursla for a variety of time intervals in 2005

Cherrapunjee	Month	1 min	5 min	10 min	30 min	60 min	24 h
	March	4.0	15.0	18.8	26.0	39.9	156.6
	April	2.5	10.8	20.1	30.5	37.5	131.6
	May	13.8	14.7	19.6	32.4	35.9	80.9
	June	2.9	12.2	21.6	59.8	106.2	392.3
	July	2.7	12.0	21.0	51.9	75.2	228.4
	August	13.7	46.5	52.8	53.9	55.5	231.3
	September	1.8	7.9	14.4	22.9	31.6	87.3
	October	1.4	6.3	10.5	13.5	14.0	54.6
Mawsynram	Month	1 min	5 min	10 min	30 min	60 min	24 h
	March	2.6	9.3	14.5	19.8	26.7	100.9
	April	2.8	9.0	13.4	19.1	26.4	107.0
	May	2.5	9.8	17.7	31.2	51.5	82.4
	June	2.5	10.6	20.1	58.1	94.0	384.3
	July	2.0	7.4	12.3	28.6	41.4	325.5
	August	1.9	8.0	15.3	40.5	63.7	279.0
	September	1.8	6.7	11.2	19.8	29.2	124.9
	October	1.5	4.0	5.6	8.3	11.0	74.1
Pynursla	Month	1 min	5 min	10 min	30 min	60 min	24 h
	March	3.1	10.7	17.2	23.2	24.5	117.0
	April	2.5	10.5	20.1	31.7	36.5	103.7
	May	2.4	7.8	12.7	19.9	21.0	40.2
	June	12.5	28.9	28.9	38.0	59.3	315.2
	July	1.7	6.1	11.6	21.8	30.5	200.5
	August	1.9	9.2	17.7	45.2	57.7	174.9
	September	13.0	31.3	31.3	31.7	47.8	79.3
	October	1.1	4.7	6.7	7.6	7.8	19.2

7.3.2.3.3 Maximum Rainfall Intensity

Maximum rainfall intensity was analysed for 1 min, 5 min, 10 min, 30 min, 60 min, and 24 h in 2005 (Table 7.3). Maximum rainfall intensity for 1-min intervals oscillates around 3 mm in the pre-monsoon season and around 2 mm in the monsoon season. However, there were also some cases when rainfall intensity was several times higher – Cherrapunjee in May (13.8 mm min^{-1}) and in August (13.7 mm min^{-1}) as well as Pynursla in June (12.5 mm min^{-1}) and September (13 mm min^{-1}). It is important to note that rainfall intensity this high did not occur at the Mawsynram in 2005 (Table 7.3).

The largest rainfall intensity for a 5-min interval was noted at Cherrapunjee in August (46.5 mm). Somewhat lower intensity was recorded for Pynursla in June (28.9 mm) and September (31.3 mm). The maximum rainfall intensity at Mawsynram occurred in June (10.6 mm) and was more than four times lower than that for Cherrapunjee.

The highest 10-min rainfall intensities were noted for Cherrapunjee in August (52.8 mm) as well as Pynursla in September (31.3 mm). Peak intensities for 30-min were noted primarily in June at Mawsynram and Cherrapunjee as well as in August at Pynursla. Maximum rainfall intensity for 60-min and 24-h was noted in June for all three study sites.

In summary, the highest rainfall intensities were noted at Cherrapunjee – up to the 10-min interval in August and in the case of 30-min or longer intervals in June. The highest intensities at Pynursla (up to 10-min intervals) were noted in September and were higher than intensities noted at Mawsynram. Peak intensities at Pynursla for intervals longer than 30 min were noted in June. Peak rainfall intensities were noted at Mawsynram only in June. The highest 24-h intensities were noted for Cherrapunjee, with lower values at Mawsynram and even lower values at Pynursla. Maximum rainfall intensity increase evenly at Cherrapunjee and Mawsynram, while at Pynursla there is a substantial increase between 60-min intensity values and 24-h intensity values. In the pre-monsoon season, rainfall intensity (for up to 60-min) increases evenly, but increase several-fold in the case of the 24-h period in comparison with the monsoon season. The highest values of rainfall intensity were noted for the post-monsoon season at Pynursla for intervals up to 60 min.

7.4 Discussion and Conclusions

The analysis of spatial and temporal rainfall variations at three sites in the southern part of the Meghalaya Plateau revealed large differences across a relatively small study area. Mawsynram receives the highest rainfall amounts among the three studied sites. This site is found on the westernmost exposure, on the way of southwestern winds that bring in a large amount of humidity, which favors rainfall. The second factor is the location of Mawsynram at the highest elevation with the best water vapor condensation conditions. Lower rainfall at the Pynursla can be explained in part by its distance from the southern edge of plateau. Sato (2013) notes that the leeward effect increases with distance from the edge of plateau.

Most of the rainfall between March and October falls within the monsoon season i.e. Cherrapunjee 74.2 %, Pynursla 78.2 %, and Mawsynram 78.3 %. Similar values have been noted for the study area previously (Jagannathan and Bhalme 1973; Guhathakurta and Rajeevan 2008; Ahasan et al. 2010; Singh 2013). About 5 % of each month is affected by rainfall during the pre-monsoon and post-monsoon seasons, while about 40 % of August (monsoon month) is affected by rainfall. The number of days with a rainfall total exceeding 100 mm during monsoon season reach 25, 23 and 18 at Cherrapunjee, Mawsynram, and Pynursla respectively.

Maximum daily rainfall exceeding 300 mm (Cherrapunjee and Mawsynram) and 249 mm (Pynursla) occurred in June. The highest rainfall intensity in 30 min, 60 min and 24 h was noted in June – primarily in Cherrapunjee. Yet on the same days when the daily rainfall exceeded 100 mm at both Cherrapunjee and Mawsynram, higher rainfall intensity was noted at Mawsynram. Between the middle of June and the end of August, mean daily rainfall amounts were the highest at Mawsynram. Periods with daily rainfall exceeding 100 mm lasted 1 or 2 weeks and were intertwined with periods of low rainfall. The intertwining of both periods is associated with synoptic scale circulation. The study area experiences strong westerly winds (velocity >15 m s^{-1}) during major rainfall periods. These winds are noted mainly in the middle and upper troposphere in line with the baric gradient vector and tend to push a large amount of water vapor towards the southern slopes of Meghalaya (Fujinami et al. 2011).

At the same time, humid southwestern winds blow north at altitudes of up to 1 km (Murata et al. 2008; Sato 2013). These winds originate from the northern part of the Bay of Bengal where center of convection is located (Sato 2013). In addition, the winds encounter an orographic barrier (Meghalaya and Himalayas), which triggers downpours (Murata et al. 2008; Sato 2013).

The diurnal rainfall pattern follows a distinct pattern of peak rainfall at nighttime. On the other hand, minimum hourly rainfall occurs between 15:00 and 20:00. Work by Kataoka and Satomura (2005) points to a key role of southwesterly winds whose speed increases at night, which is why humid air masses can move faster across the studied plateau leading to higher rainfall. There exists a close relationship between "time with rainfall" and diurnal rainfall patterns (correlation coefficient = 0.93). On average, it rains for 30 min per hour at nighttime. On the other hand, it rains (on average) for only 5 min per hour around 17:00. In addition, a similar pattern can be discerned in the case of mean hourly rainfall intensity.

Mean monthly rainfall intensity was the highest in June and during the pre-monsoon season at all three sites. While mean monthly rainfall intensity patterns are similar for the Cherrapunjee and Mawsynram, the differences appear with respect to mean hourly rainfall intensity. Large differences between the two sites in the pre-monsoon season are caused by a small number of days with rainfall relative to the monsoon season as well as by extreme rainfall events that occur from time to time. The Cherrapunjee possesses two maximums – at 18:00 and 12:00 – that exceed 0.27 mm min^{-1}. Maximum rainfall intensity at the Mawsynram occurs between 10:00 and 11:00. Mean daily rainfall intensity at both sites equals 0.16 mm min^{-1}. During the monsoon season, daily rainfall intensity patterns tend to closely follow overall diurnal rainfall patterns. Characteristic maximum intensity values noted around midnight reflect high daily rainfall totals; mean daily rainfall intensity equals 0.19 mm min^{-1}.

The highest rainfall intensity in the pre-monsoon season are associated usually with short downpours (Prokop 2007). Higher maximum intensity values in March and April are characteristic of Cherrapunjee, but in May, higher intensity values are noted for Mawsynram due to the onset of the monsoon in the area. Peak intensity rainfall events were recorded in June. Maximum rainfall intensity values were quite similar for Cherrapunjee and Mawsynram. Intensity values for July and August decreased compared with June. Higher maximum rainfall intensity were noted for Cherrapunjee throughout the monsoon season.

7.5 Final Remarks

Research has shown that despite being found at similar elevations, each of the three studied sites substantially differs in terms of the rainfall amount. The Pynursla is located east of the other two sites and receives 2000 mm less rainfall than Mawsynram and Cherrapunjee, which are located less than 20 km away. This is the case despite the fact that the three sites are characterized by a comparable number of hours with rainfall. In addition, the amount of rainfall increases markedly towards Mawsynram, which suggests that even higher rainfall amounts may be expected in areas west of Mawsynram – in the southern part of the Meghalaya Plateau.

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Chapter 8
Rainfall Structure for Cherrapunjee and Mawsynram in Northeast India

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Abstract Cherrapunjee and nearby Mawsynram (located 15 km away) receives the highest annual rainfall in the world. On the basis of annual, monthly and daily rainfall for the period 1980–2004 was made an attempt to show similarities and differences between the two sites. Analysis was supported by investigation of hourly course of rainfall at Cherrapunjee. The interaction between large-scale circulation and the local topography plays a crucial role in rainfall spatial distribution at Cherrapunjee and Mawsynram. Despite their close proximity, differences in annual rainfall can reach several thousand millimeters. Results has shown that mean annual rainfall totals are higher at Mawsynram, while the mean number of days with rainfall is higher at Cherrapunjee. In addition, the number of days with rainfall up to 50 mm is higher at Cherrapunjee, while the number of days with rainfall exceeding 100 mm is higher at Mawsynram. However, the rainfall distribution for the summer monsoon season as well as the precipitation concentration index at both sites are similar.

Keywords Extreme rainfall • Rainfall concentration index • Cherrapunjee • Mawsynram • Meghalaya Plateau

8.1 Introduction

Cherrapunjee, locally known as Sohra, is located in northeast India. It is known as a place with the highest annual rainfall in the world. This reputation has been part of the research literature for decades (Jennings 1950; Dhar and Farooqi 1973). Cherrapunjee is located in an area affected by monsoon circulation, which yields more than 11,000 mm of rainfall per year, on average (O'Hare 1997; Starkel and Singh 2004; Soja and Starkel 2007). Research in the early 1980s demonstrated that the neighboring gauging site of Mawsynram may be actually getting more rainfall than does Cherrapunjee (Dhar and Nandargi 1996; Soja 2003; Murata et al. 2007).

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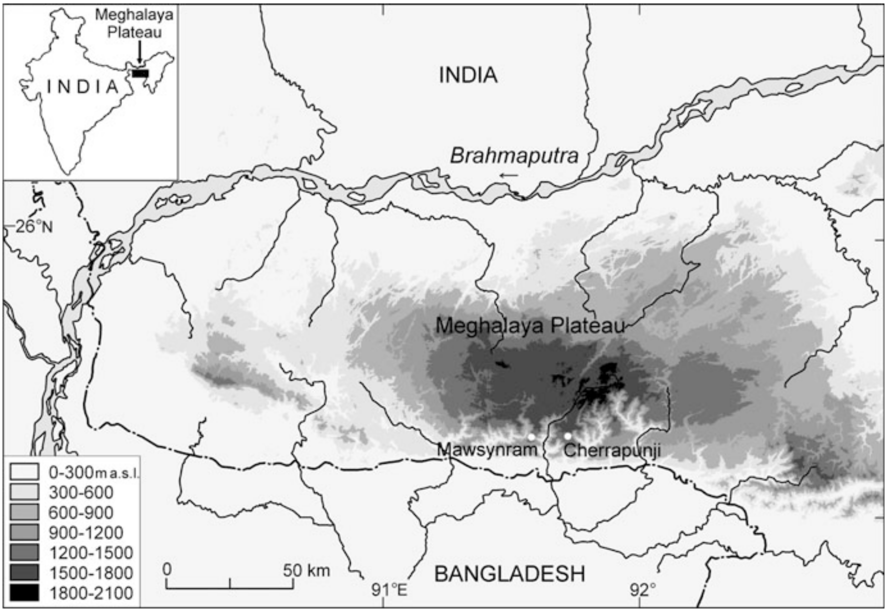

Fig. 8.1 Location of Mawsynram and Cherrapunjee

In light of the economic benefits of tourism, both towns now claim to be "the rainiest place" on Earth. On the other hand, the severe rains have a substantial socio-economic impact on Meghalaya and neighboring Bangladesh which are dependent on agriculture and prone to natural hazards (Dhar and Nandargi 2000; Hofer and Messerli 2006).

The aim of this paper is to compare the amount and structure of rainfall at the Cherrapunjee and Mawsynram. These two sites are located in the southern slopes of the Meghalaya Plateau about 15 km away from one another in a straight line (Fig. 8.1).

8.2 Materials and Methods

The analysis is based on data collected in the course of research work in India and includes daily rainfall totals for Mawsynram (1401 m a.s.l.) and Cherrapunjee (1303 m a.s.l.) for the period 1980–2004. Data for Mawsynram were acquired from the India's Public Works Department, while data for Cherrapunjee were acquired from the India Meteorological Department (IMD) in Pune. Missing data items were filled in using the constant ratio method. This database was then used to calculate the rainfall amount ad number of days with rainfall for selected months and years as well as mean number of days per year with rainfall within certain categories.

Additional data were collected using a tippet-bucket SEBA RG-50 raingauge at Cherrapunjee for the period 1999–2002 and 2005–2007. These data with temporal resolution of 1 s were used to calculate hourly rainfall amounts. Authors used the Indian Standard Time (IST) that is Coordinated Universal Time (UTC) +5.5 h.

A precipitation concentration index (PCI) was also calculated (Oliver 1980).

$$\mathrm{PCI} = 100\left\{\Sigma x^2/\left(\Sigma X^2\right)\right\} \tag{8.1}$$

where x is average monthly rainfall, X is total rainfall in following months. The index scale ranges from less than 10 for evenly distributed rainfall to 100 for extreme rainfall distribution.

8.3 Results

8.3.1 Annual Rainfall

Analysis has shown that the mean annual rainfall total for the period 1980–2004 was 12,770 mm for Mawsynram and 11,851 mm for Cherrapunjee. The highest annual rainfall total at Mawsynram over the course of the 25-year study period was noted in 1984 and equaled 25,446 mm. The corresponding peak total for Cherrapunjee occurred in 1998 and equaled 17,953 mm. Hence, the highest rainfall total for Mawsynram was almost 7500 mm higher than that for Cherrapunjee. Annual rainfall totals at Cherrapunjee were higher than those at Mawsynram on only three occasions in the 25-year study period (Fig. 8.2). In most cases, the differences were small – less than 5 % of the annual rainfall total.

Unlike in the case of meteorological organizations in Europe and North America, the IMD defines a day with rainfall as a day with at least 2.5 mm of rainfall (Starkel and Singh. 2004). The average number of days with rainfall per year in Cherrapunjee was 157, while in the case of Mawsynram 146. The classification of rainfall in terms of the number of days with rainfall of a different height made it possible to more accurately assess the structure of rainfall at the studied sites (Fig. 8.3). Four groups were identified using the IMD definition of rainfall. It must be noted that both studied sites apart extremely high rainfall amounts are characterized by a majority of rain-free days throughout the year. Cherrapunjee has a total of 157 days with rainfall per year, i.e. 43 %, while Mawsynram has 146 days, i.e. 40 %. Defining a day with rainfall as a day with at least 0.1 mm of rainfall does not substantially change the above proportions.

The most frequently encountered rainfall total is 10–50 mm per day. A total of 64 days per year in the 10–50 mm category were recorded at Cherrapunjee, while at Mawsynram, the number of days in this category was only 54. On the other hand, Mawsynram possessed the higher number of days (44 per year) with more than 100 mm of rainfall, while for Cherrapunjee it was only 38 days per year. In addition,

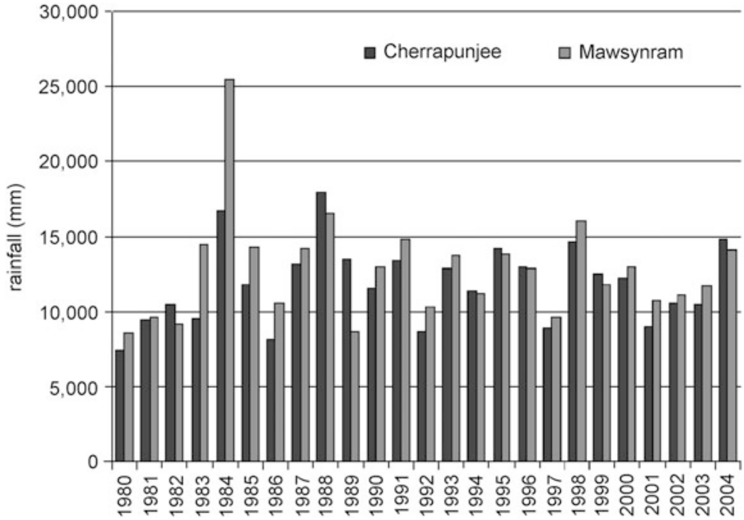

Fig. 8.2 Annual rainfall totals for Cherrapunjee and Mawsynram in 1980–2004

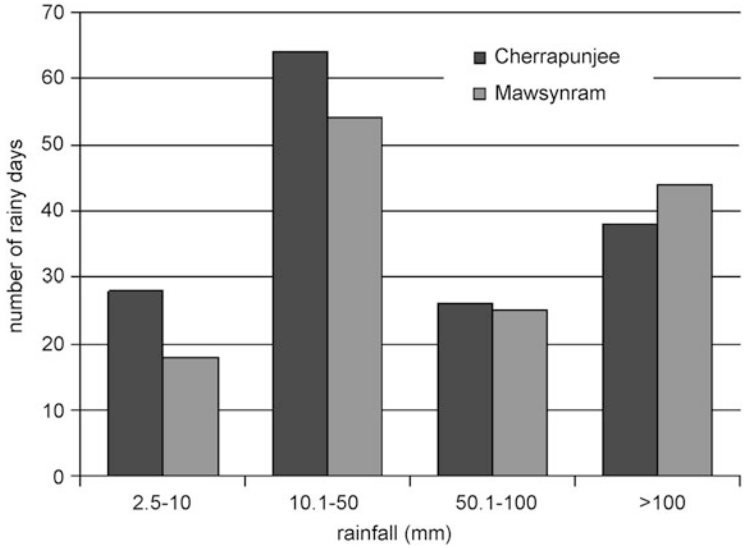

Fig. 8.3 Mean number of days per year with rainfall within given categories at Cherrapunjee and Mawsynram in 1980–2004

82 % of days with more than 100 mm of rainfall at Cherrapunjee consist of days with up to 300 mm of rainfall. The corresponding value for Mawsynram is 91 %, while 18 % of days in the year with more than 100 mm of rainfall exceed 300 mm of rainfall per day. The corresponding value for Cherrapunjee is 9 %. Hence,

Mawsynram more often experiences very high rainfall, but Cherrapunjee more often experiences extremely high rainfall.

The rarest categories of rainfall are the 2.5–10.0 mm, with 28 days in Cherrapunjee and 18 days in Mawsynram, and the 50–100 mm category with about 25 days in of each site. It may be assumed that the larger number of days with rainfall in the 2.5–50 mm category at Cherrapunjee is responsible for the larger mean number of days with rainfall at this site. An analysis of all days of the year with rainfall at Cherrapunjee has shown this to be true, which also helps explain the larger number of rainy days at Cherrapunjee, despite the smaller annual rainfall total compared with Mawsynram.

8.3.2 Monthly Rainfall

The highest mean monthly rainfall totals were recorded in July: 3780 mm at Mawsynram and 3130 mm at Cherrapunjee (Fig. 8.4). The lowest totals were noted in December and January – only about 20 mm at each site. High rainfall is noted already in May with rainfall at 1300–1400 mm. This increases during the summer monsoon (July–September) to 2500 mm in June at both sites and more than 3000 mm at Cherrapunjee as well as more than 3500 mm at Mawsynram in July. While the rainfall amount at each site is similar during the winter (December–January), the rainfall amount at Mawsynram is larger than that at Cherrapunjee during the summer monsoon as well as during the pre- and post-monsoon seasons. This difference is at its peak in July at more than 650 mm. On the other hand, it is frequently the case that no rainfall is recorded in both December and January at the two sites.

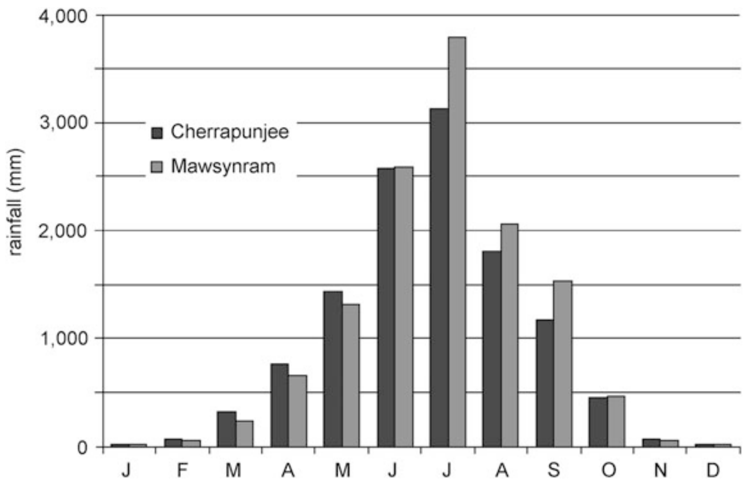

Fig. 8.4 Mean monthly rainfall totals at Cherrapunjee and Mawsynram in 1980–2004

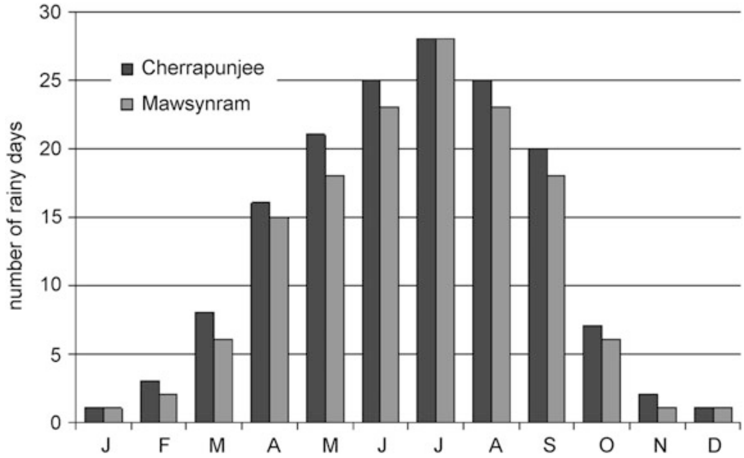

Fig. 8.5 Mean monthly number of rainy days at Cherrapunjee and Mawsynram in 1980–2004

The highest mean monthly number of days with rainfall is 28 at both sites in July, while the smallest number of days is during winter (Fig. 8.5). The number of days with rainfall increases in May to 18 days at Mawsynram and 21 days at Cherrapunjee. During the summer monsoon this number increases in June to 23 at Mawsynram and 25 at Cherrapunjee. The maximum is noted in July – 28 days at each site. The number of days with rainfall in August and September remains similar to that for May and June. The number of days with rainfall is largest at Cherrapunjee relative to Mawsynram in all months, except for July. Given the generally low number of days with rainfall during the dry season, the difference in the number of days with rainfall is negligible.

The number of days with rainfall varies significantly by month and rainfall amount. Usually only 1 or 2 days with rainfall (less than 50 mm) are noted in November, December, January, and February. The highest number of days with more than 100 mm of rainfall at Cherrapunjee is noted between May and August, while at Mawsynram it is noted between May and September. The maximum is reached in July at 11 days for Cherrapunjee and 14 days for Mawsynram. The mean number of days with more than 100 mm of rainfall is 42 for Masynram and 33 for Cherrapunjee between May and August.

Days with more than 100 mm of rainfall are usually days with up to 300 mm of rainfall at each site (Figs. 8.6 and 8.7). Days featuring 500–700 mm of rainfall have been also noted – more often in Cherrapunjee. In addition, a highest daily rainfall of 1563 mm was recorded on 16 June 1995 in Cherrapunjee. Days with 11–50 mm of rainfall in the period between April and September are noted more often (three additional days) in Cherrapunjee than Mawsynram. Days without rainfall dominate the winter at Cherrapunjee and Mawsynram. In March and April are noted first days with rainfall in the 50–100 mm range. The number of days with more than 100 mm of rainfall increases in May and peaks in July.

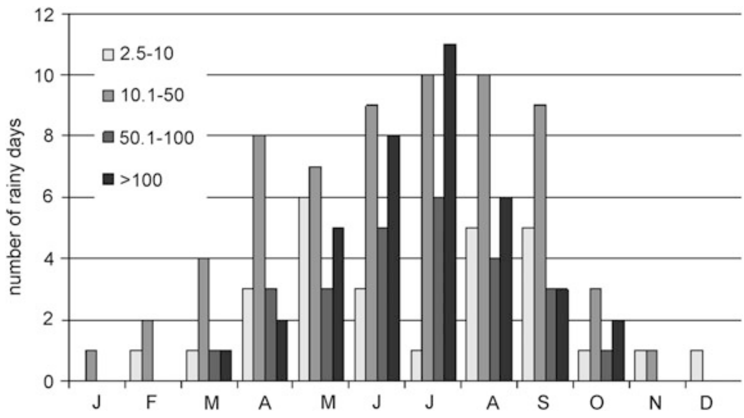

Fig. 8.6 Number of rainy days per month for selected rainfall categories (mm) at Cherrapunjee in 1980–2004

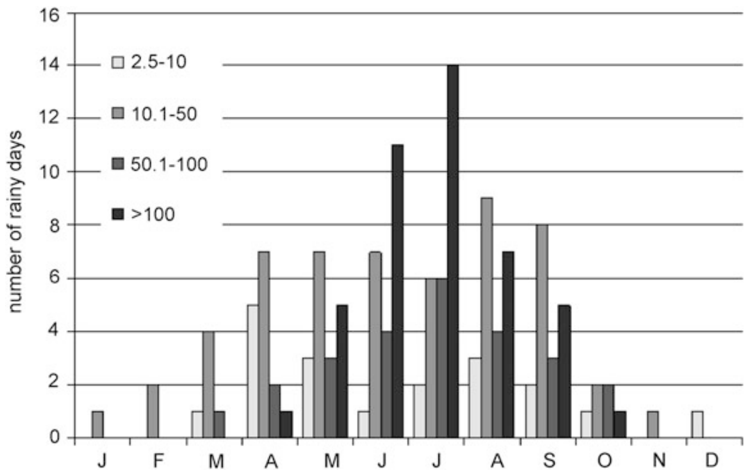

Fig. 8.7 Number of rainy days per month for selected rainfall categories (mm) at Mawsynram in 1980–2004

8.3.3 Hourly Rainfall

The hourly rainfall cycle for Cherrapunjee is analysed using data obtained using SEBA RG-50 raingauge with temporal resolution of 1 s. Mean hourly rainfall totals were calculated based on 92 days with daily totals exceeding 100 mm for the monsoon season (Fig. 8.8). The rainfall maximum falls between 11:00 at night and 5:00 in the morning. The highest mean value (11.6 mm) is noted between 2:00 and 3:00 after midnight. The rainfall minimum occurs between 13:00 and 18:00 in

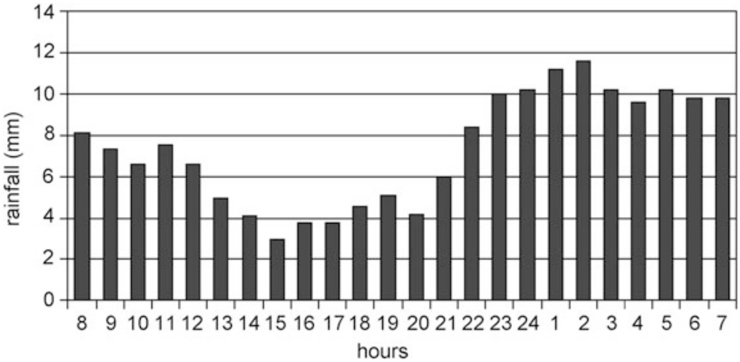

Fig. 8.8 Mean hourly rainfall at Cherrapunjee for the monsoon season in 1999–2007

the afternoon, while the lowest mean value (3.0 mm) is noted between 15:00 and 16:00 in the afternoon.

Many consecutive rainy days which are observed in monsoon climate regions bring thousands of millimeters of rainfall to Cherrapunjee and Mawsynram. A total of 33 rain events were analyzed for Cherrapunjee with rainfall totals over 250 mm. Close to half the rain events (45 %) began between 20:00 and 23:00 at night, which is also a time when mean hourly totals begin to increase. Only one case was noted between 5:00 and 10:00 in the morning. The rain events lasted between 18 and 156 h – and their mean value was 80 h. Rain events lasting longer than 100 h constituted 24 % of the studied time, while those lasting less than 50 h constituted 21 % of the studied rain events.

Short rain events are characterized by high intensity. The highest mean hourly intensity (0.53 mm min^{-1}) was observed with the shortest 18-h rain events, while the maximum hourly intensity (1.73 mm min^{-1}) was observed with a 20-h rain events. Rain's events duration can be used to identify two types of rainfall: (1) long-lasting rainfall, (2) short-lasting downpours characterized by high intensity. The mean daily rainfall intensity ranged from 0.09 mm min^{-1} (20th July 1999 and 6th August 2005) to 0.61 mm min^{-1} (31st May 1999). The largest number of cases were classified in the 0.11–0.20 mm min^{-1} intensity category (63 %) and the 0.21–0.30 mm min^{-1} intensity category (24 %). The mean intensity for all the studied cases was 0.20 mm min^{-1}.

One basic approach to describe the annual rainfall cycle is to use a concentration index (Eq. 8.1). The paper employs a formula (1) proposed by J.E. Oliver (1980) who compared the annual rainfall cycle for different climate zones. This index works well for cases such as monsoon climates dominated by a single 5 or 6 month rainfall cycle. Oliver's mean PCI for annual rainfall totals equals 19.69 for Mawsynram and 19.24 for Cherrapunjee in the studied 25-year period (Fig. 8.9). Rainfall in June, July, and August at Mawsynram constitutes 66 % of the annual rainfall amount. At Cherrapunjee, the corresponding value is 64 %. Rainfall between May and September constitutes 88 and 86 % of the annual rainfall amount,

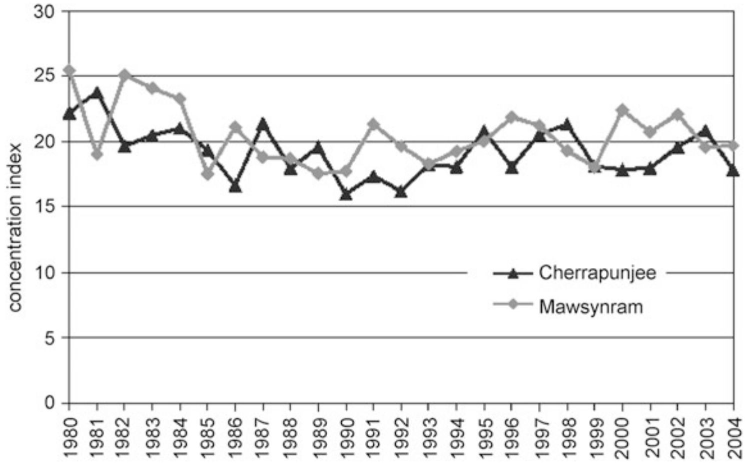

Fig. 8.9 Precipitation concentration index (Eq. 8.1) for annual rainfall totals at Cherrapunjee and Mawsynram in 1980–2004

respectively. The slightly larger concentration of rainfall at Mawsynram is the result of higher rainfall in July, which is often associated with rainfall in excess of 300 mm per day.

8.4 Final Remarks

The analysis shows that mean and maximum annual rainfall totals are higher for the Mawsynram, as are mean rainfall totals for the rainiest month of the year – July. The differences are most likely the result of better water vapour condensation conditions at 100 m higher located Mawsynram in comparison to Cherrapunji (Table 8.1).

While rainfall totals are higher for the Mawsynram, the number of days with rainfall is higher for the Cherrapunjee. In addition, the number of days with rainfall

Table 8.1 Selected rainfall data for Cherrapunjee and Mawsynram in 1980–2004

	Cherrapunjee	Mawsynram
Mean annual rainfall (mm)	11,851	12,270
Max. annual rainfall (mm)	17,953	25,446
Precipitation concentration index	19.24	19.69
Mean annual number of days with rainfall	157	146
Mean annual number of days with 10–50 mm rainfall	64	50
Mean number of days with >100 mm rainfall	38	44
July – mean rainfall (mm)	3130	3780
July – mean number of days with rainfall	28	28

up to 50 mm is higher at Cherrapunjee, while the number of days with rainfall exceeding 100 mm is higher at Mawsynram. The concentration of rainfall at both sites is almost identical. Furthermore, the rainfall distribution for the summer monsoon season for both sites is similar. The rainfall maximum for both sites occurs between 23:00 and 5:00, while the rainfall minimum is observed between 13:00 and 18:00.

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Chapter 9
Land Use and Land Cover Changes in the Area with the Highest Rainfall in the World (Meghalaya Plateau, India): Causes and Implications

Paweł Prokop

Abstract The Meghalaya Plateau is an area where human activity has caused deforestation which, in the extreme monsoonal rainfall conditions, has led to soil degradation and expansion of grasslands at higher altitudes. The shortening of the shifting cultivation cycle resulting from the demographic growth, is generally considered to be the major cause of deforestation and the degradation of soil in this area. Analysis of the land use and land cover indicates a lack of response of the forest and grassland area to the population increase in the twentieth century. The radiocarbon dating of iron slags and supplemented data from historical reports has led to the formulation of a new hypothesis, connecting the deforestation with the 2000 year-old practice of charcoal production for smelting iron. High rainfall and impoverished soil together with the annual practice of vegetation burning are the causes of the present day stability of the land use and land cover system inherited from the past.

Keywords Land use/cover • Extreme rainfall • Population • India

9.1 Introduction

The land use and land cover (LULC) changes, especially the deforestation of the higher elevated tropical areas was commonly linked to population growth leading to an expansion of the shifting cultivation (Allen and Barnes 1985). However recent studies show that tropical forests usually have a long history of human influence and LULC changes are the result of multiple causative factors acting in various geographical locations and historical contexts (Mather and Needle 2000; Geist and Lambin 2002; Carr et al. 2006; Davidar et al. 2010).

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The Meghalaya Plateau located in Northeast India is one of the rainiest inhabited environments on Earth, with more than 11,000 mm of precipitation recorded annually in Cherrapunjee. High monsoonal rains, severe earthquakes, hills with steep slopes and shallow soil cause that any human intervention in such a fragile ecosystem can lead to rapid and long lasting LULC changes (Starkel and Singh 2004; Soja and Starkel 2007; Migoń and Prokop 2013).

The most characteristic feature of the LULC system of the Meghalaya Plateau is the prevalence of grasslands over an area of a few thousand square kilometres at elevations of above 1000 m a.s.l. At the same time, the remnants of the climax vegetation of the sacred groves is the evidence that the plateau must have been covered by forest in the past. These forest patches have dense vegetation with a high diversity of species and have been protected through the ages by the local people for religious reasons (Bor 1942; Tiwari et al. 1999).

Scientific exploration of the Meghalaya Plateau began only in the first half of the nineteenth century. There is evidence from the historical accounts of British naturalists that grasslands in the central part of the plateau had existed before the nineteenth century (Walters 1832; Pemberton 1835; Hooker 1854; Oldham 1854). However, first studies undertaken by ecologists considered the shortening of the shifting cultivation cycle resulting from the population increase, to be the major cause of deforestation and the soil degradation of the plateau (Toky and Ramakrishnan 1981, 1982; Ramakrishnan 1992). Studies based on satellite images from the period 1975–2001 also indicate a decrease in the forest area in the Meghalaya Plateau. Unfortunately, the rates of deforestation reported differ considerably between authors due to the different methodologies adopted, the complex land use system and large spatial biodiversity (Department of Space 1985; Roy and Tomar 2001; Roy and Joshi 2002; Lele and Joshi 2009; Forest Survey of India 2013).

The objective of the present study is, to evaluate the LULC transformation of the tropical catchment in the monsoonal climate with the highest rainfall on a global scale. The causes and implications of LULC changes are analyzed by looking at the impact of natural extreme events and human activity.

9.2 Study Area

The study was conducted in the Umiew catchment on the southern slope of the Meghalaya Plateau which is exposed to humid southwest monsoon winds from the Bay of Bengal (Fig. 9.1). The catchment covers 493.7 km^2 and stretches from the highest point of the plateau (Shillong Peak) to the foothills. The area encompasses two typical landforms with different LULC of the southern slope: the grass covered hilly plateau and the forested deep canyons.

The upper part of the Umiew catchment is built up of gneisses and quartzites intruded by granites. Crystalline basement is covered near Cherrapunjee and Mawsynram by horizontally bedded sandstones and limestones several hundreds

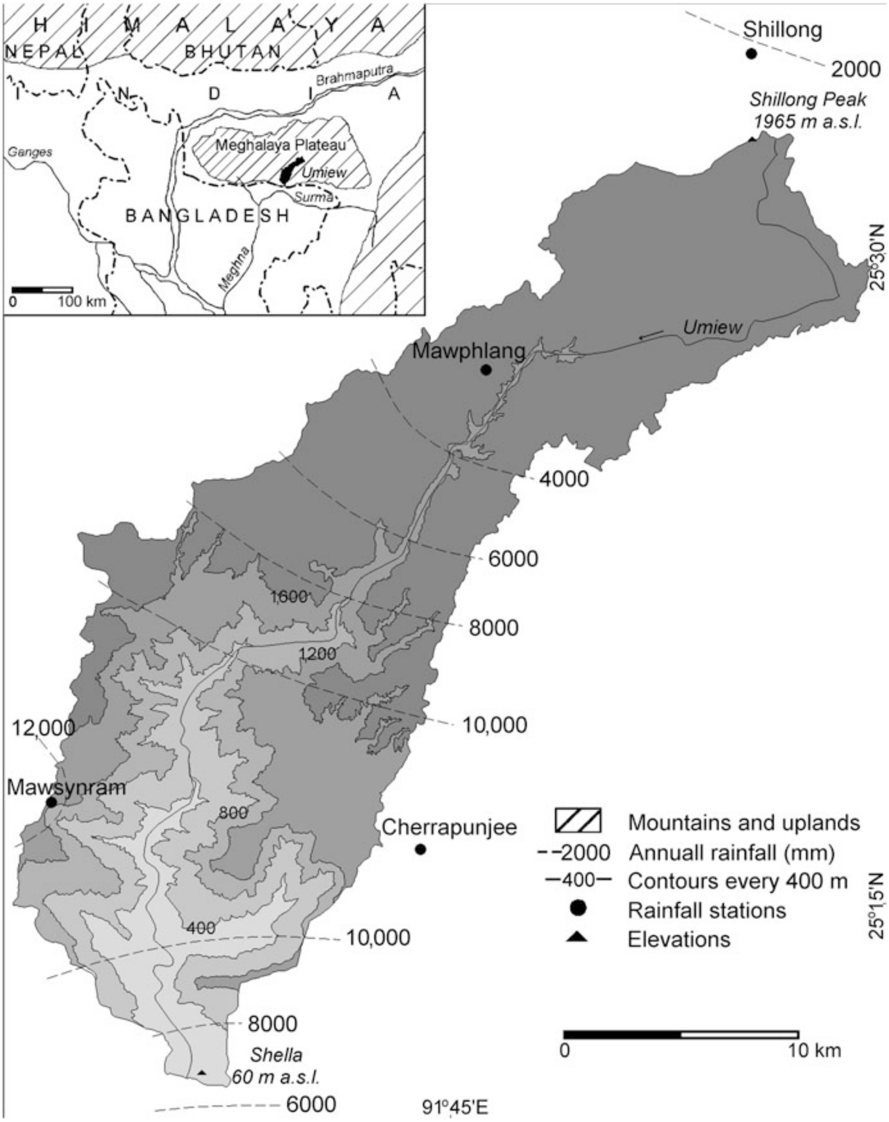

Fig. 9.1 Location of the study area

metres thick. This part of the catchment has a hilly landscape with relief energy 50–150 m. The tectonic fault truncates the southern margin of the catchment that forms a very steep scarp. The escarpment is interrupted into several spurs by a system of canyons with depths up to 1000 m.

The climate is monsoonal with the warm rainy season spanning from June to September and the dry cool winter. The mean annual air temperature is closely related to elevation and varies between 24 °C in the Umiew outlet to 16.6 °C in

Shillong. The mean annual rainfall is strongly modified by the relief and varies from 6000 mm in the foothills to 11,000–12,000 mm in Cherrapunjee and Mawsynram that are located at the spurs. The rainfall decreases with the distance from the edge of plateau to 2200 mm in Shillong.

The soils are acidic and nutrient deficient, due to the leaching resulting from high rainfall. Finer textured soils are found in the upper part of catchment, where was preserved the thicker weathered deposits in places. The soils of sedimentary complex around Cherrapunjee and Mawsynram are severely degraded with an armoured layer on the surface, ranging up to 20 cm or with bare rock exposure. The soils in adjoining canyons are usually rich in humus and shallow resulting from mass movements.

Natural subtropical evergreen forest is preserved mostly on the steep slopes of deep canyons. Secondary grasses with dense root system typical for steppe areas cover most of the hilly plateau. Subtropical broad-leaved forest which is assumed has grown on the hilly plateau in the past is today found, only in small patches of sacred groves (Khiewtam and Ramakrishnan 1993). The secondary pine forest is scattered between grasslands above 1600 m a.s.l. In this part of the catchment, rice and potatoes are important cultivation crops.

9.3 Material and Methods

LULC data were derived from the Survey of India topographic maps at scale of 1:63,360 for the year 1910 and a Landsat 7 ETM+ multispectral satellite image with panchromatic sharpening, to spatial resolution of 15 m for 2010. Additionally a maps at scale of 1:50,000 for the year 1966, was used for checking tendencies of LULC change and creating a digital elevation model (DEM).

Three LULC classes were delimited: forest, grassland and agriculture (rice). The boundaries between them were manually digitized on screen using visual interpretation technique. The increase or decrease the areas in such classes, were obtained by intersecting and generating the matrices of change-no change for different years.

A digital elevation model (DEM) was created from digitized contours at intervals of 20 m. The proportion of forests in the 200-m classes of elevation, were assessed from the DEM and LULC data for 1910 and 2010. A separate map with settlement was prepared on the basis of census data, collected for the villages for 1901 and 2011 (Risley and Gait 1903; Government of India 2011). The centre of each village was located with the help of topographic maps and the use of GPS during fieldwork. The total population was calculated in the 200-m classes of elevation and the population density was assessed for each class.

Historical reports were used as the sources of supplementary information concerning impact of heavy rains and earthquakes on LULC as well as spatial pattern of mineral extraction and population in distribution in the nineteenth century (Oldham 1854; Hooker 1854; Allen 1858; Hunter 1879; Oldham 1899).

9.4 Results and Discussion

9.4.1 Land Use and Land Cover Changes in the Umiew Catchment During the Last 100 Years

Time series analysis shows the very stable proportions between the forests and grasslands in the Umiew catchment over the last 100 years (Fig. 9.2). These two land cover classes occupied 94 % of the study area in 1910. Most of the land cover changes occurred within the hilly plateau which covers 300 km^2. The deforestation processes have taken place in the most populated upper part of the catchment, although this was compensated by afforestation and natural forest regrowth in less accessible areas. Changes in the forest area and population density show that although population density grew from 23 inhabitants per km^{-2} in 1901 to 138 inhabitants per km^{-2} in 2011, the forest area also expanded from 44.6 % in 1910 to 46.1 % in 2010. As the result the total forest area has not changed significantly.

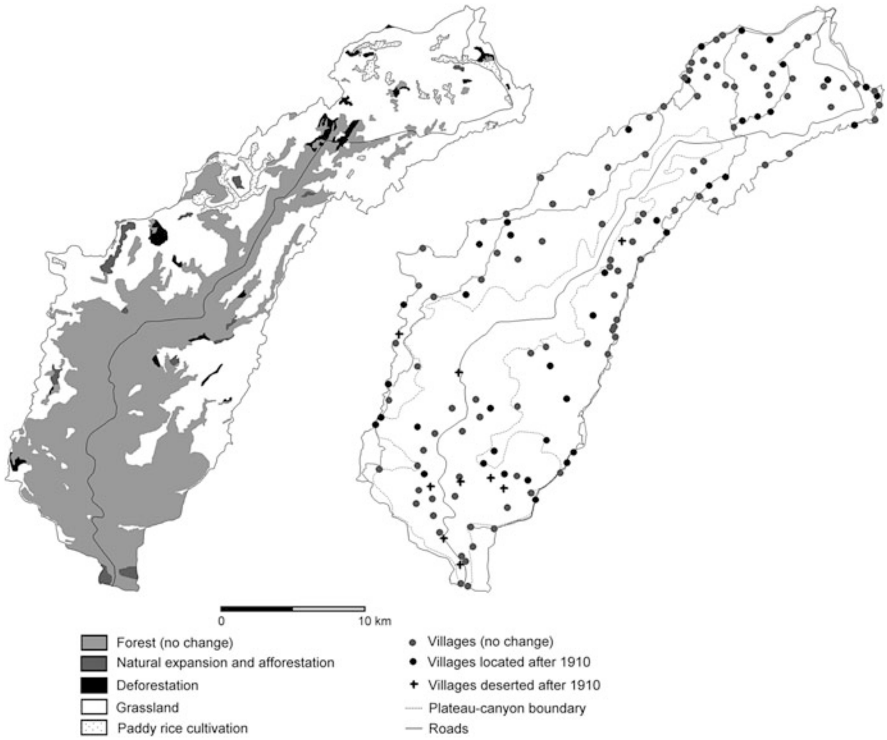

Fig. 9.2 Land use/cover 1910–2010 and settlement (villages) 1911–2011 changes in the Umiew catchment

The number of villages in the Umiew catchment increased from 109 to 138 between 1901 and 2011 (Allen 1906; Government of India 2011). The new villages were located in the vicinity of Shillong town and along main roads after 1910. About 92 % of the population is concentrated within the hilly plateau where the average density reached 211 inhabitants per km^{-2} in 2011. The rest of the inhabitants are spread over 24 villages on the steep slopes of the canyon, where the average density is only 24 inhabitants per km^{-2}. The changes in forest area and location of new villages occurred at the expense of grasslands.

Agricultural land with rice cultivation occupies 2.4 % of the catchment area and it still covers the same flat valley bottoms in the upper part of the Umiew catchment as in 1910. This is the most stable land use form that is connected with the relief. It is not possible to compare in detail changes in potato cultivation. The small fields on the slopes comprising tens of square metres are usually intermixed with grasslands surrounding rice cultivation. As a result they have not been delineated on the maps. Analysis of the satellite image shows that they cover about 3 % of the catchment area. Around Cherrapunjee and Mawsynram, the practice of agriculture is scarce due to the degraded soil. Only about 10 % of the population of both spurs is engaged in cultivation limited to home gardens and small orange plantations on the surrounding forested slopes (Government of India 2011).

Detailed information about LULC dynamics provides the analysis of forest and population changes with elevation. The proportion of forest in relation to the elevation fluctuates between 80 % and 95 % up to 1200 m a.s.l. (Fig. 9.3). Above this altitude, it constantly decreases to only a few percent in the highest part of the catchment. This distribution is closely related to relief and population density.

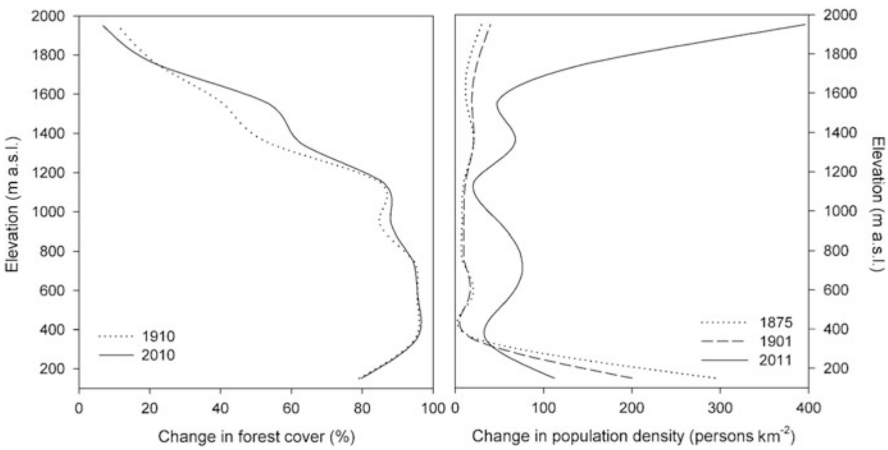

Fig. 9.3 Changes in the proportion of forest area for the period 1910–2010 and population density for the period 1875–2011 with elevation in every 200 m in the Umiew catchment. Data for the forest area: 1910 – topographic map at scale of 1:63,360, 2010 – NDVI vegetation index on the basis of satellite image Landsat ETM+. Data for the population density: 1875 and 1901 – calculations on the basis of data from *semi-independent states* in the Umiew catchment, Hunter 1879, Allen 1906, 2011 – villages in the East Khasi Hills District (Government of India 2011)

However, in the past this correlation was not so distinct. Especially noteworthy are the lowest and highest parts of the catchment, where the course of population changes was different. The lower part of the catchment, below 400 m a.s.l., had already been partly deforested due to intensive surface limestone mining before the nineteenth century (Walters 1832). The heavy earthquake of 1897 caused the destruction of villages and orange and areca-nut plantations in the Umiew canyon, resulting in the migration of people to higher elevations and the location of new villages there (Oldham 1899; Becker 1915). This trend became fixed after a border demarcation between India and Bangladesh in 1947 and the liquidation of the border checkpoint near Shella. Both reduced population pressure and supported forest regrowth.

The central part of the canyon is severely dissected by a dense drainage system and the proportion of forest here exceeds 95 %. The steep slopes and scarps of the canyons are not suitable for developing settlements and agriculture. The percentage of the flat areas usually covered by grasses growing on degraded soil, increases above 1200 m a.s.l. In the upper part of the catchment, near Shillong which also suffered in consequence of the earthquake, reductions of population were small. After the restoration throughout twentieth century, settled agriculture developed here under intense human pressure to meet the commercial needs of Shillong – the capital of Meghalaya (Tiwari 2003; Prokop and Poręba 2012). Between 1901 and 2011, the population of Shillong increased from 9621 to 354,325 and population density in the 20-km zone around Shillong rose from 20 to 400 persons km^{-2} (Allen 1906; Government of India 2011). This part of the Umiew catchment has the lowest proportion of forest at about 7 %.

9.4.2 The Impact of Rainfall and Earthquake Induced Mass Movements on LULC Changes

The Umiew catchment is prone to mass movements due to extreme rainfall, heavy earthquakes and a large proportion (more than 50 % of the total area) of steep slopes above 15°. Mass movements are not recorded systematically although it is clear from historical sources that they were a prominent feature.

The first information we find in T. Oldham's (1854) report which described the effect of landslides and debris flows, encompassing the area of the canyon from Mawphlang to Shella (cf. Fig. 9.1). This occurred on 14 June 1851. In Cherrapunjee during the whole of June 3773 mm of rain fell. Probably after several successive rainy days, the saturated weathered cover on the slopes became triggered. Landslides blocked the water flow in the rivers. That caused the water level to rise locally by up to 15 m in the Umiew river bed (the maximum water level rises to 4 m during a monsoon season) and cut the base of the steep slopes. The forested slopes were scored with gullies and deep ravines, extending from the level of the water up to their summits. So the large effects of landslides induced only by rainfall were not described in the Umiew catchment till the present time. However, historical sources

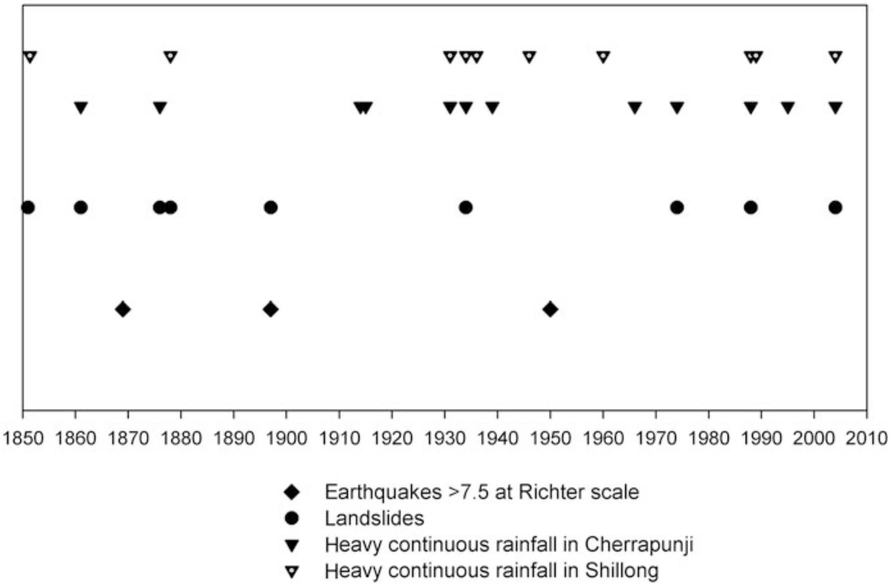

Fig. 9.4 Extreme events registered in the Umiew catchment during the last 150 years

give evidence of large landslides occurring in 1861 (Becker 1915), 1876 (Sherer 1879) and 1898 (Allen 1906, Fig. 9.4).

The present day information about the impact of landslides on LULC is provided by the analysis of satellite images. Conditions favouring mass movements appeared when heavy rainfalls and floods occurred in North-East India in 1988 (Mirza 2003). The annual rainfall in Cherrapunjee reached 17,925 mm and exceeded the long term average by 63 %. The Shillong station recorded 3807 mm, the highest annual total in the period 1867–2000. Two series of heavy continuous rainfalls occurred 4–7.07. with totals of 2019 mm in Cherrapunjee and 522 mm in Shillong as well as 24–27.08. with totals of 1989 mm in Cherrapunjee and 441 mm in Shillong. This type of extreme rainfall occurs once every 10 years in the Umiew catchment.

Landslides of an area of tens of hectares originated in the middle part of the Umiew catchment at an altitude of 1000–1500 m a.s.l. and slopes inclined 30–40° (Fig. 9.5). Similarly significant, as in 1851, was the saturation of the weathered cover and the rapid rise in water level in the river bed. The sequence of Landsat TM images shows part of the Umiew catchment in 1987 before the landslide was triggered, in 1988 just after the sliding and in 1991 – 3 years after mass movements. Fresh landslides and an aggraded river bed are clearly visible on the image from 1988 (Fig. 9.5). The undercut forested slopes were the main source of the material deposited on the river bed. During the monsoon season, it was carried out and deposited within 10 km of the foothills of the plateau (Fig. 9.5). Traces of landslides are still visible on the image from 1989 (not shown), but they cannot be detected on the image from 1991. Landslides were overgrown by vegetation within 2–3 years.

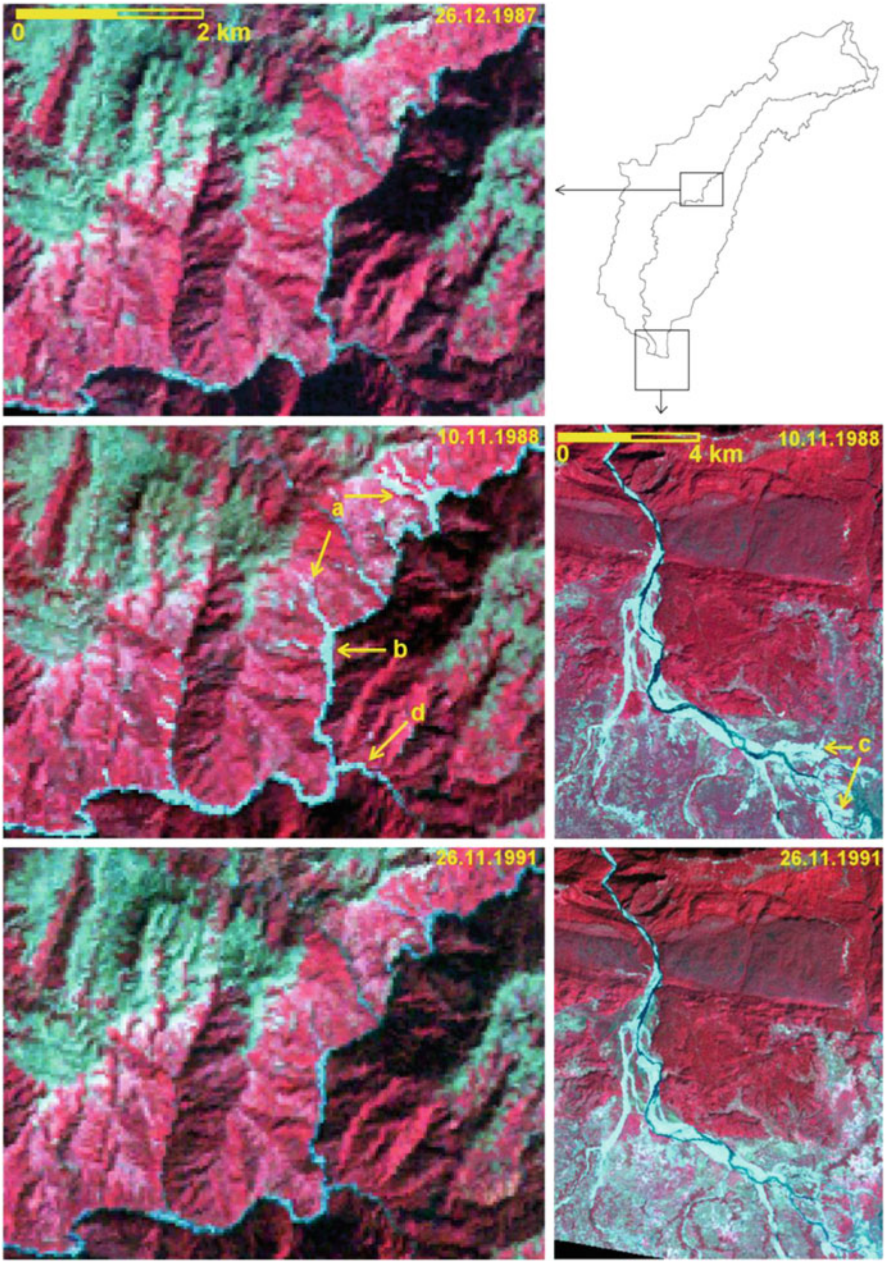

Fig. 9.5 The sequence of Landsat TM images of the part of the Umiew catchment. Image from 1987 shows the situation before landslide triggering, one from 1988 after landslides and one from 1991 – 3 years after mass movements, (**a**) active landslides, (**b**) aggraded river bed with material from slopes, (**c**) sediment deposition at the foothills on the Bengal Plain, (**d**) river bed filled with material from slopes in the catchment where landslides are not visible on the satellite image

Mass movements as a consequence of large seismic events usually run rapidly and have greater extents than those induced by the impulse of rain. Earthquakes of M = 7.0–7.9 in Papua-New Guinea trigger landslides which damage 8–16 % of the forest area every 100 years, while rainfall-induced landslides destroy only 3 % of the forest area in the same period (Garwood et al. 1979).

Three severe earthquakes (M > 7.5) have occurred in the vicinity of the Umiew catchment over the last 150 years, in 1869, 1897 and 1950. The 1869 Cachar earthquake and 1950 earthquake in the mountains on the Indo-China border due to the remoteness of the epicentre were not remarkable for the natural environment of the Umiew catchment (Godwin-Austin 1868–1869, Kingdom-Ward 1953).

The earthquake of 12 June 1897 in the Meghalaya Plateau was the largest (M = 8.0) intraplate event in the last two centuries recorded in the Indian subcontinent. Much of what is known about the effects of this event comes from R.D. Oldham's (1899) report and his subsequent account of 3 months of heavy rains and aftershock activity following the earthquake.

Amounts of rainfall in 1897 were close to the long term averages (Cherrapunjee 11,870 mm, Mawphlang 4137, Shillong 2229 mm). Rainfall was relatively small in June but during the first 5 days of September in Cherrapunjee rainfall exceeded 2000 mm.

Slopes in the lower section of the Umiew canyon became devoid of vegetation cover for a length of 1000 m from the base of the horizontally bedded sandstones to the river beds (Becker 1915). The enormous amount of weathering material delivered into streams caused the aggradation of the river bed to 4 m. Large landslides formed barriers over 10 m height. The break of the barriers caused successive cuttings at the base of the slopes by flowing water and caused new landslides (Oldham 1899).

Shella, and villages situated in its vicinity, were severely damaged by rock falls and landslides. The estuary of the Umiew lost navigation possibilities in consequence of the river bed aggradation. This stopped the extraction and transport of limestone and created a crisis in local market centres. The loss of their source of income caused the impoverishment of the inhabitants (Allen 1906). This gave the impulse to the migration of people from the foothills to higher elevations and the location of new villages there. From that time, the area of the estuary of Umiew never recovered from the devastation to its former condition. The population of Shella village decreased from 4000 in 1901 to only 74 inhabitants in 2011 (Risley and Gait 1903; Government of India 2011).

The maps of the Umiew valley at scale of 1:63,360 from 1910 show a vegetation cover developing on former landslides. Nowadays, it is not possible to visually distinguish the secondary forest from the primary one in the Umiew canyon. This is evidence that the recovery time of vegetation is similar to other tropical regions (Garwood et al. 1979; Guariguata 1990). The recurrence period of severe earthquakes of above 500 years in Meghalaya (Sukhija et al. 1999; Bilham and England 2001) is sufficient for the development of tropical forests with the same floristic composition as in the primary forest.

9.4.3 The Role of Agriculture Expansion in the Transformation of LULC System of the Umiew Catchment

The expansion of the shifting cultivation as a consequence of the pressure of the increasing number of the population is generally considered as the major cause of LULC changes in the Meghalaya Plateau (Toky and Ramakrishnan 1981, 1982; Mishra and Ramakrishnan 1983). The presented hypothesis supports the fact that similar vegetation formations reckoned of savannas are visible in other regions of North-East India, in the mountains on the borderland with Myanmar as well as in Thailand and the Philippines (Yadava 1990; Whitmore 1991).

Shifting cultivation is the predominant form of agriculture at the lower elevations of Meghalaya. The radiocarbon dating of charcoal from alluvia in the Krishnai River in Garo Hills (the oldest date 1370 ± 155 years BP, Sukhija et al. 1999) suggest that shifting cultivation may have been a common form of land use from at least the Early Medieval Period. The utilization of fire increased the disturbances of forest ecosystems, but the survival of shifting cultivation up to the present day indicates that it remained in equilibrium with the environment for a long time.

Shifting cultivation is considered to be an environmentally suitable land use where the fallow period is long enough to regenerate the soil capacity and vegetation cover. This balance can be achieved when population density is relatively low. It can usually support 10–20 persons km^{-2}, because only 10 % of the area is under cultivation at any one time (Whitmore 1991). The system is destructive for vegetation and soil when the fallow period is excessively shortened or the period of cultivation is extended for too long.

However, the relationship between population growth and a shortening of the fallow period leading to forest decline is not so obvious in case of the Umiew catchment. The most substantial changes in land cover were prior to 1910. The deforested area was at that time considerably greater than would result from the forest clearing under the shifting cultivation and firewood collection to supply the needs of the inhabitants. The first estimations in the middle of the nineteenth century show that population density did not exceed 8 persons km^{-2} in the study area (Hunter 1879). This is below the lowest limit (10–20 persons km^{-2}) of population above which the shifting cultivation system is assumed to be dangerous for forest ecosystems (Whitmore 1991). There was also no close relationship between population density and the forest distribution at that time (cf. Fig. 9.3).

LULC changes could not have a straightforward response to the high demographic growth because it started only in the 1950s. The location of new villages and expansion of agriculture occurred mainly at the expense of grasslands not natural forests. Dense forest survived in the canyons and deep incised valleys within the hilly plateau, because of their inaccessibility.

9.4.4 Effects of Minerals Extraction and Processing on Deforestation of the Umiew Catchment

The quarrying and processing of iron ore, limestone and coal was the oldest occupation pursued by the inhabitants of the Meghalaya Plateau, followed by agriculture. As far as deforestation related to shifting cultivation encompassed the whole Meghalaya, the mineral extraction was concentrated in its central part (Fig. 9.6). The first British naturalist to visit Meghalaya Plateau at the beginning of the nineteenth century noted the iron furnaces and numerous traces of former iron ore excavations that were scattered over a large part of the hilly plateau (Walters 1832; Hooker 1854; Oldham 1854, Fig. 9.6). The principal source of iron-ore was the granite outcrops in the northern part of the Umiew catchment. The iron smelting required large quantities of charcoal produced from local forests. Estimated calculations show that at the annual level of export of about 1866 tonnes of iron (Allen 1858), at least 13.5 km^2 of the forest had to be cut down for the production of the charcoal (Prokop 2007). Most of the iron was sent to the Bengal Plains where it was used in the building of river boats. Official statistics show iron as a main export resource in 1858 (Allen 1858), but it does not appear in the statistics in 1876 (Hunter 1879). The iron industry died out in the second half of the nineteenth century, as a result of the import of cheap iron from England.

Traces of the iron industry are still visible as deposits of washed sand with charcoal, clay tuyeres and slag. Radiocarbon dating of the charcoal from iron slag near Nongkrem revealed evidence of continuous iron smelting in the Umiew catchment spanning the last two millennia (Prokop and Suliga 2013, cf. Fig. 9.6).

Probably, the cutting of trees used for charcoal production was the major cause of deforestation and soil degradation in the Umiew catchment. Deforestation of the natural forest, combined with heavy rainfall, initiates high rates of overland flow. Continuous accelerated slope wash has caused the removal of the finer soil particles and the formation of an armoured layer (Froehlich 2004). Annual vegetation burning favoured the subsequent expansion of grass on soils which were deficient in fine particles and nutrients (Ramakrishnan and Ram 1988).

Limestone and coal mining contributed less or later to their share in LULC changes. The limestone quarrying was concentrated in the foothills of the southern slopes (Oldham 1854). It caused the deforestation of only a few square kilometers along the Indo-Bangladesh border. The first coal mines were established by the British government in 1840, but by 1848, the number had declined as a result of low revenues (Oldham 1854). Most of the mining activity of private land holders is today located within the already degraded grasslands and their expansion has taken place over the last few decades (Umashankar et al. 1993).

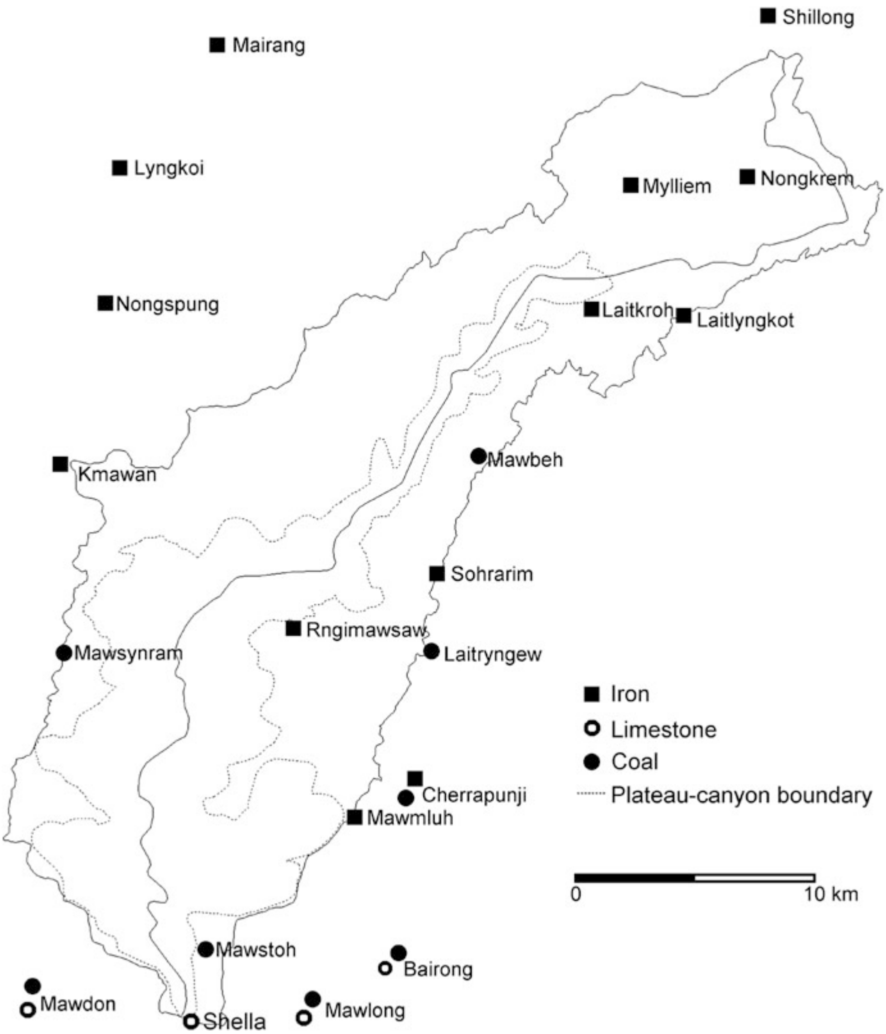

Fig. 9.6 The distribution of main centers of quarrying and processing of mineral resources in the Umiew catchment in the middle of the 19th on the background of the forest map from 1910

9.5 Conclusions

The Meghalaya Plateau has adequate precipitation and temperature to support forest growth, but at its higher elevations, grasslands prevail growing on degraded soil. Remnants of climax vegetation of sacred groves are evidence that the plateau must have been covered by forest in the past. Assessment of LULC changes indicates that they can be as a result of three factors: natural extreme events, expansion of shifting cultivation and mineral extraction.

Heavy rainfall and earthquakes are the important natural driving forces of temporary LULC changes in the Umiew catchment. The relative importance of extreme events differs between the two major landforms and is connected with the land use forms: the forested deep canyons and the degraded grass covered hilly plateau.

Canyons with steep slopes are most sensitive to the mass movements triggered by extreme rainfall. The continuous heavy rain with 20–25 % of the annual precipitation in 3–4 days cause landslides on steep but forested slopes. These types of extreme events occur once in every few decades. Landslides are overgrown by vegetation within 2–3 years, which is a similar recovery time to other tropical regions.

The large seismic events $M > 7.0$ cause larger damage to the vegetation in canyons than that induced by the rain impulse. The recurrence period of above 500 years of earthquakes is sufficient for the development of the tropical forest with the same floristic composition and the biomasses in the primary forest.

On the contrary, the most deforested and degraded area of plateau covered by grass is very resistant to extreme events. Only cultivatable land with thicker weathered cover in the northern part of the Umiew catchment is prone to rainfall-induced landslides.

Rainfall and earthquake-induced mass movements are not able to permanently deforest a large area of the plateau. Thus, the factor which contributed to the LULC changes of the Umiew catchment was man. The effects of the human impact depend on the local environmental conditions and land use history.

The shortening of the shifting cultivation cycle, as a consequence of the demographic growth is generally considered as the major cause of deforestation and soil degradation on the Meghalaya Plateau. However, this hypothesis contradicts evidence from the historical accounts of British naturalists that grasslands in the upper part of the plateau had existed before the nineteenth century, i.e. before the substantially increased population in the second half of the twentieth century. The deforested area was at that time considerably greater than would result from the forest clearing for the shifting cultivation and firewood collection to supply the needs of the inhabitants.

The close relationship between the location of the centres of iron manufacture in the middle of the nineteenth century, and the deforested areas on the hilly plateau, led to the formulation of the hypothesis that a major cause of deforestation was the production of the charcoal required for the smelting of iron. Radiocarbon dating of charcoal from slag, confirms that the smelting of iron in this part of Meghalaya was begun at least 2000 years ago and continued up to the middle of the nineteenth century.

The deforestation of the plateau above 1000 m a.s.l., combined with heavy rainfall initiated slope wash and favoured the subsequent expansion of grasslands on soil which was deficient in fine particles and nutrients. Land degradation was facilitated additionally by naturally shallow soil, developed on sedimentary rocks, whose occurrence coincides with the range of high rainfalls. Although iron production fell in the second half of the nineteenth century, the land degradation was so advanced that the forest could not recover to its original form. High rainfall and degraded soil together with the annual burning and grazing of vegetation now play a prominent role in preserving the degraded land inherited from the past.

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Chapter 10
Maximum Flow and Maximum Specific Flow in a Small Catchment Affected by an Extreme Rainfall Near Cherrapunjee in Northeast India

Tomasz Bryndal and Roman Soja

Abstract Hourly rainfall data collected in the Maw-Ki-Syiem experimental catchment (area: 0.22 km^2) during the period 1999–2009 and the application of hydrological models (SCS-CN and GIUH – previously calibrated and verified) allowed for the analysis of the hydrological response of the catchment, located in an extremely humid monsoonal climate. Due to a lack of detailed hydrological data, this area has rarely been investigated. Its hydrological response was investigated in relation to different types of rainfall, recorded in pre-monsoon, monsoon and post-monsoon seasons in 2002 and 2005. Hydrographs revealed rapid response of the catchment to rainfall. The rising limb and recession limb were very steep and coincided with hourly rainfall patterns. The observed hydrological response consisted of maximum flow of less than 2.5 $m^3\ s^{-1}$ and a maximum specific flow of less than 11 $m^3\ s^{-1}\ km^{-2}$ for rainfall of less than 20 mm h^{-1}. Precipitation higher than 80 mm h^{-1} resulted with a maximum flow peak higher than 20 $m^3\ s^{-1}$ and maximum specific flow exceeding 90 $m^3\ s^{-1}\ km^{-2}$. These high flow peaks occurred in pre-monsoon and monsoon seasons but not in the post-monsoon season. Maximum specific flow in the Maw-Ki-Syiem experimental catchment is one of the highest recorded values in the world. Relationships such as rainfall intensity versus maximum flow and rainfall intensity versus maximum specific flow were evaluated in order to support the estimation of maximum flow and maximum specific flow on the basis of rainfall data (easily accessible for this region) for small catchments near the town of Cherrapunjee.

Keywords Extreme rainfall • Maximum specific flow • Small catchments • Meghalaya Plateau

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10.1 Introduction

In the town of Cherrapunjee, which is located in the southern part of the Meghalaya Plateau in northeast India, the daily rainfall may exceed 600 mm; with the maximum reaching 1563 mm on the 16th of June, 1995 (Rakhecha and Clark 1999; Soja et al. 2004; Guhathakurta 2007). The environmental setting of the southern part of the Meghalaya Plateau has experienced significant human impact in the last few decades. Progressing deforestation, extensive cultivation, and overgrazing of slopes combined with surface mining have resulted in the degradation of soil cover, exposure of hard rocks, and formation of an impermeable residual crust on the surface (Soja and Starkel 2007). These conditions accelerate the water cycle. Taking into account the local climate and environmental conditions, high values of maximum specific flow may be expected in a catchment located in this region. Investigations focusing on hydrological aspects are especially important in a regional context in this case. The Meghalaya Hills represent only 2 % of the area of the Ganges, Brahmaputra and Meghna river basins, although they account for 20 to 25 % of the rainfall input between March and June (Hofer 1997). The rainfall-runoff relationship on the southern slopes of the Meghalaya Hills is very important in the flood processes frequently noted in nearby Bangladesh (Hofer and Messerli 2006; Murata et al. 2008).

Most studies of the Cherrapunjee region focus on the analysis of rainfall data (e.g. Dhar and Farooqui 1973; Soja and Singh 2004; Murata et al. 2007; Sato 2013) due to the availability of such data. However, there is lack of information related to the hydrological response of river catchments located in such extremely humid regions. Catchments near the Cherrapunjee are ungauged and there is lack of hydrological research on this area, except a study conducted in the Maw-Ki-Syiem experimental catchment by a Polish-Indian group of researchers (Starkel et al. 2002; Froehlich et al. 2003).

The goals of this paper are: (1) to present and evaluate the hydrological response of a small catchment, located in one of the most humid regions of the world, to rainfall recorded during the pre-monsoon, monsoon and post-monsoon seasons, (2) to estimate the highest values of peak flow and specific flow, (3) to relate these values to world records, (4) to evaluate the following relationships: (a) rainfall intensity vs. maximum flow, and (b) rainfall intensity vs. maximum specific flow, in order to support the estimation of these hydrological parameters on the basis of rainfall data, which are readily accessible for this region.

10.2 Study Area

The study area includes a part of the Meghalaya Plateau located near the town of Cherrapunjee in northeast India (Fig. 10.1a, b). This area is mainly composed of sandstone and siltstone, with thin limestone complexes in its southern part (Prokop

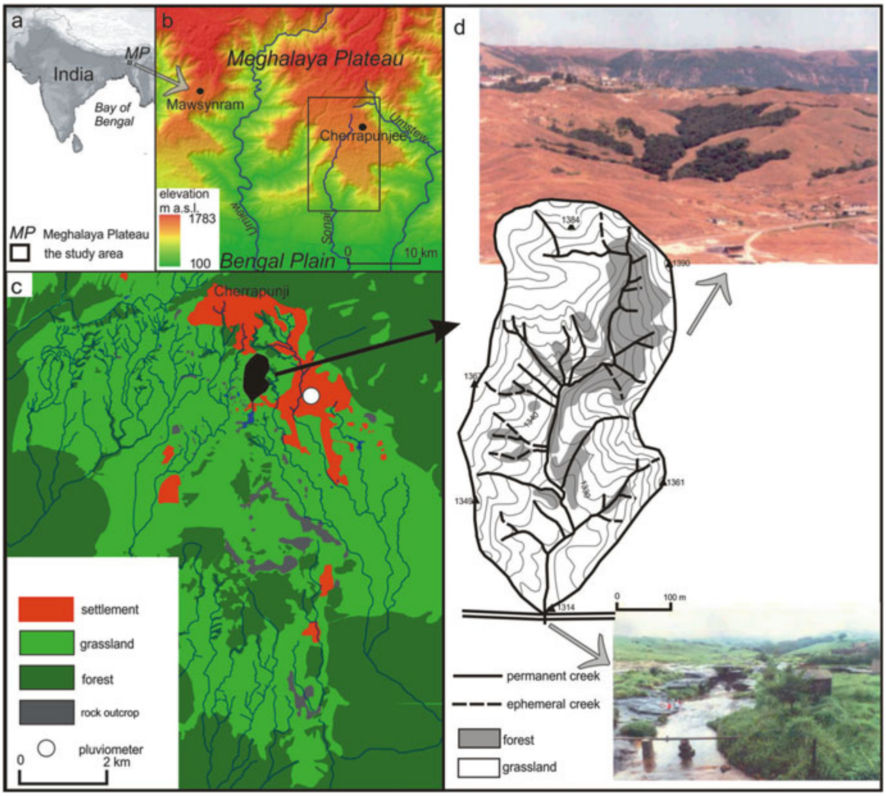

Fig. 10.1 Study area, (**a**) location of the Meghalaya Plateau, (**b**) relief of the southern part of the Meghalaya Plateau near Cherrapunjee, (**c**) land cover and location of the Maw-Ki-Syiem experimental catchment, (**d**) Maw-Ki-Syiem experimental catchment (Based on Starkel et al. 2002 and Bryndal et al. 2015)

and Starkel 2004). The study area is restricted by a high escarpment incised by canyons up to 1000 m deep (Fig. 10.1b).

The canyons are covered by evergreen sub-tropical forest (Starkel et al. 2002, Fig. 10.1c). An undulated surface of plateau with relief energy up to 150 m represents typical relief in this area. Small, bare escarpments of natural and anthropogenic origin occur sporadically here (Fig. 10.1c). The soil cover usually ranges from 25 to 50 cm, with a gravelly pavement of 2 to 5 cm (Starkel et al. 2002). The drainage system is composed of small streams (1–2 km in length) running in the NNE-SSW direction, which drain catchments up to 9 km^2 in area (Fig. 10.1b, c). The natural environment in this area has been significantly transformed by human activity. Grassland covers most of this area (Fig. 10.1c) and forest-scrub-type vegetation occupies steeper parts of slopes (Froehlich et al. 2003). Temperature varies from 16 °C in the winter to 26 °C in the summer. Most of the rain falls during the summer (May-September) because of the effective SW monsoon

(O'Hare 1997a, b). The mean annual rainfall in Cherrapunjee is reach 11,371 mm (based on 149 years of data – 1852–2000) with variances ranging from 6283 mm in 1951 to 23,663 mm in 1974 (Soja and Singh 2004). Daily maximum probable rainfall is estimated at 1500 to 1600 mm (Rakhecha and Clark 1999).

The Maw-Ki-Syiem catchment was identified in 2000 for the purpose of research work on hydrological and geomorphological processes and soil erosion in northeast India (Fig. 10.1c). The catchment has an area of about 0.22 km^2. It is 900 m long and 300 to 400 m wide (Fig. 10.1d). The catchment slopes down from a ridge found at about 1400 m of elevation in the North to an elevation of 1314 m measured close to a bridge along a road. Southward of the road, the studied stream crosses a flat basin and after 200 to 300 m it disappears into a karst ponor. The catchment is drained by one main stream with several short, permanent tributaries. Valley density in the area is 14 km km^{-2}. Most of the studied slopes are deforested and grassland areas dominate the area (Fig. 10.1d). Shrub forests, directly affected by man, occupy about 15 % of the catchment area. Comparing with other parts of the Cherrapunjee, the Maw-Ki-Syiem catchment is fully representative of the general region in terms of relief, soil properties, and land use (Starkel et al. 2002).

10.3 Material and Methods

High-resolution rainfall data, required in the investigation of the hydrological response of the Maw-Ki-Syiem catchment, were obtained using a German-made SEBA Hydrometric pluviometer, installed near the catchment (Fig. 10.1c); the pluviometer was operated in 1999–2009 and recorded rainfall with 1-s time resolution and a 0.1 mm step. Pluviometer data were converted into hourly and monthly rainfall totals. Then the time-series data were analyzed and periods (months/days) with the highest rainfall were selected for the pre-monsoon, monsoon and post-monsoon seasons of 2002 and 2005.

Hourly rainfall data were converted into river runoff data using the SCS-CN and GIUH hydrological models (Soil Conservation Srevice-USDA 1972; Rodriguez-Iturbe and Valdes 1979). Both models had been previously calibrated and verified on the basis of rainfall-runoff data collected in the Maw-Ki-Syiem experimental catchment (Bryndal et al. 2015). This solution is commonly used if there is no data or there is a lack of continuous hydrological data (Jain at al. 2000; Vikrant and Sinha 2003). It is notable that GIUH-supported models have been successfully applied in studies of the hydrological response of catchments in neighboring regions (Bhaskar et al. 1997; Jain et al. 2000; Kumar et al. 2007; Bhadra et al. 2008; Nguyena et al. 2009; Narayan et al. 2012). Hydrographs allowed for an evaluation of the hydrological response of the Maw-Ki-Syiem catchment to rainfall recorded in three main rainfall seasons of the year.

The resulting hydrographs were analyzed and values of peak flow (Qmax – m^3 s^{-1}) and specific flow (qmax – m^3 s^{-1} km^{-2}) were studied in context of rainfall intensity (mm h^{-1}). This enabled the development of relationsheeps, which may be used for the estimation of peak flow on the basis of rainfall data, which are readily available for this region.

The maxima of the flow recorded in the Maw-Ki-Syiem were evaluated by looking at the envelope curve developed by Herschy (2002).

$$\mathrm{Qmax} = 100\mathrm{A}^{0.8} \tag{10.1}$$

where Qmax is maximum flow ($m^3\ s^{-1}$), and A is catchment area (km^2), which describes the highest values of the maximum flow in the world in catchments smaller than 100 km^2.

Hydrological characteristics of flood waves in the Maw-Ki-Syiem catchment have been also evaluated via a:

1. comparison with 10 highest maximum specific flow (qmax) values ($m^3\ s^{-1}\ km^{-2}$) recorded during local flash flood events throughout the world (Rodier and Roche 1984; Costa 1987) and by looking at the envelope curve (Gaume et al. 2009):

$$\mathrm{qmax} = 350\mathrm{A}^{-0.4} \tag{10.2}$$

   that describes the maxima of specific flow throughout the world.
2. comparison with 10 highest maximum values of the flood index *K*, calculated for local flash flood events. The *K* index, developed by Françou and Rodier (1969):

$$K = 10 - \left(1 - \frac{\mathrm{LogQmax} - 6}{\mathrm{LogA} - 8}\right) \tag{10.3}$$

   allows to compare the magnitude of a flood wave regardless of catchment area; therefore, it may be considered a better measure for the purpose of comparison.

10.4 Results and Discussion

10.4.1 General Characteristics of Rainfall in 2002 and 2005 in Cherrapunjee

Annual rainfall patterns in Cherrapunjee are typical of the monsoonal climate with a very distinct rainy summer (March–November), when the active–break cycles of rainfall occur, and dry winter (December–February) when precipitation seldom occurs (Das 1951). Three distinct seasons may be distinguished: pre-monsoon, monsoon, and post-monsoon (Das 1951). Table 10.1 shows monthly precipitation in 2002 and 2005 against the background of mean multiannual values calculated for the years 1902–2000.

Table 10.1 Rainfall (mm) recorded in 2002 and 2005 (Bryndal and Soja this study) in the Maw-Ki-Syiem catchment and average values for Cherrapunjee in the years 1902–2000 (Soja and Singh 2004)

Months	Seasons	Monthly rainfall 1902–2000	Seasonal rainfall 1902–2000	Monthly rainfall in 2002	Seasonal rainfall in 2002	Monthly rainfall in 2005	Seasonal rainfall in 2005
Jan	Winter	20		14		—	
Feb		52		1.5		—	
Mar	Pre-monsoon	227	2317	267	2191 (95 %)	428	1492 (64 %)
Apr		685		1099		464	
May		1405		825		600	
Jun	Monsoon	2608	8157	3131	7481 (92 %)	1859	6095 (75 %)
Jul		2632		2507		1836	
Aug		1791		1066		2024	
Sep		1126		777		376	
Oct	Post-monsoon	485	549	60	136 (25 %)	434	434 (79 %)
Nov		64		76		0.1	
Dec	Winter	14		0		0.8	
Total		11,109		9822		8021	

Percentage of multiannual average rainfall is shown in brackets

Monthly rainfall in 2002 and 2005 is slightly lower than the mean values calculated for the years 1902–2000. Significantly higher monthly rainfall was recorded in April 2002 and June 2002. Higher values were also recorded in March and August 2005.

The mean multiannual rainfall for the pre-monsoon, monsoon, and post-monsoon seasons reach 2317, 8157, and 549 mm, respectively. Intra-seasonal variability is observed for every season (Table 10.1). During the pre-monsoon season, monthly rainfall almost doubles from month to month. The highest monthly rainfall occurs in the monsoon season; especially in June and July. Significantly lower rainfall is recorded in the post-monsoon season. Rainfall recorded during the pre-monsoon season in 2002 and 2005 was 5 and 36 % lower than the mean multiannual rainfall for the 1902–2002 period. For the monsoon and post-monsoon seasons, precipitation was 8 %, 75 % (2002) and 25 %, 21 % (2005) lower than the mean multiannual rainfall, respectively.

10.4.2 Rainfall Variability and Hydrological Response of the Catchment in the Pre-monsoon Season

The pre-monsoon season in the study area lasts from March until May and is characterized by low-intensity rainfall; however, heavy downpours may exceed

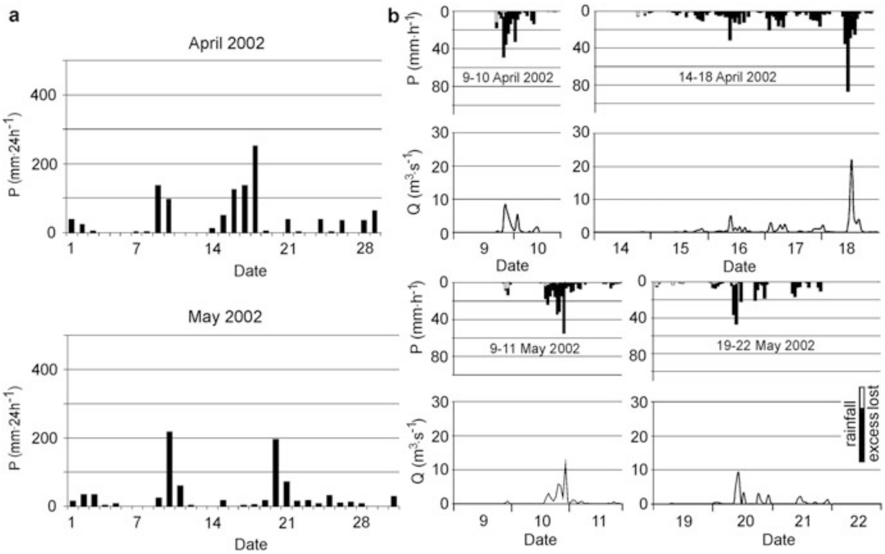

Fig. 10.2 Hydrological response of the Maw-Ki-Syiem catchment to the highest rainfall in April and May 2002, (**a**) daily rainfall, (**b**) hydrological response of the catchment to the highest rainfall, P rainfall, Q flow

300 mm per day (Froehlich et al. 2003). Downpours are not associated with monsoon circulation (Soja and Singh 2004).

Daily rainfall was usually lower than 30 mm in April and May 2002 (Fig. 10.2a). There were four short-duration (2–3 days) rainy periods when rainfall exceeded 100 mm with a maximum of 251.2 mm on the 18th of April, 2002. Hourly rainfall recorded in these rainy periods (Fig. 10.2b) exhibits typical diurnal patterns, with the highest hourly rainfall being recorded in late-evening and early-morning hours (Das 1951; Starkel et al. 2002; Kataoka and Satomura 2005; Sato 2013).

The intensity of precipitation was usually lower than 20 mm h^{-1}. Such rainfall generated flood waves with the maximum flow and maximum specific flow at less than 2.5 $m^3\ s^{-1}$ (Fig. 10.2b) and 11 $m^3\ s^{-1}\ km^{-2}$, respectively. The highest hourly rainfall recorded during this season ranged from 49 mm to 54 mm. This rainfall generated flood waves with maximum peak flow of 8 to 12 $m^3\ s^{-1}$ and maximum specific flow ranging from 36 to 54 $m^3\ s^{-1}\ km^{-2}$. Maximum rainfall of 86.5 mm h^{-1} generated a flood wave with maximum peak flow at 22.2 $m^3\ s^{-1}$ and maximum specific flow at 100.9 $m^3\ s^{-1}\ km^{-2}$.

10.4.3 Rainfall Variability and Hydrological Response of the Catchment in the Monsoon Season

The rainy summer monsoon season lasts from June to September. During these months daily rainfall varies significantly with continuous rainy periods as well as long monsoon breaks (Froehlich et al. 2003; Sato 2013). Heavy precipitation is associated with the start of the summer monsoon. On average, the monsoon season begins on the 29th of May (Das 1951); however, this date varies. In 2002 and 2005, intense rainfall started in the middle of June (Fig. 10.3a) and continued until late August. There were several intense rainy periods separated by periods with no or low-intensity rainfall. There was hardly ever rain in September; several events when daily rainfall exceeded 50 mm; with a maximum of 321.6 mm on the 29th of September, 2002.

Hourly rainfall values (Fig. 10.3b) varied substantially. On the one hand, there was a typical diurnal precipitation pattern and a general tendency towards decreases in hourly rainfall intensity in subsequent months; on the other hand, short-duration, intense, rainfall events were also noted (40–100 mm h^{-1}) in almost every month.

The hydrological response of the Maw-Ki-Syiem catchment is shown in Fig. 10.3b. The highest variability in flow was observed in June. Maximum flow of less than 2.5 $m^3\ s^{-1}$ and maximum specific flow of less than 11 $m^3\ s^{-1}\ km^{-2}$ were observed for rainfall of less than 20 mm h^{-1}. The hydrograph reveals several peaks related to high rainfall. Precipitation ranging from 70 to 80 mm h^{-1} resulted in a maximum flow peak at 17 to 20 $m^3\ s^{-1}$ and maximum specific flow exceeding 77 $m^3\ s^{-1}\ km^{-2}$.

Highest maximum flow of 27.8 $m^3\ s^{-1}$ (qmax-139 $m^3\ s^{-1}\ km^{-2}$) was generated by hourly rainfall of 103.6 mm on the 21st of June (Fig. 10.3b). Lower values of maximum flow were recorded in July, August, and September and were usually lower than 2.5 $m^3\ s^{-1}$. On several occasions, the maximum flow exceeded 5 $m^3\ s^{-1}$, with a maximum at 27.4 $m^3\ s^{-1}$ (29th of September, 2002). This peak flow was generated by a 5-h rainfall with a maximum rate of 102.8 mm h^{-1}.

10.4.4 Rainfall Variability and Hydrological Response of the Catchment in the Post-monsoon Season

The post-monsoon season lasts from October until November and includes occasional rainstorms of shorter duration, especially in October (Froehlich et al. 2003). During the study period, the highest daily rainfall was recorded in October 2005 and reached 188.8 mm (Fig. 10.4a).

Hourly rainfall, recorded during this rainfall event, was usually lower than 10 mm and generated flood waves with maximum flow of less than 1 $m^3\ s^{1}$. The highest peak flow of 5.8 $m^3\ s^{-1}$ was generated by rainfall of 32.7 $mm \cdot h^{-1}$ (Fig. 10.4b)

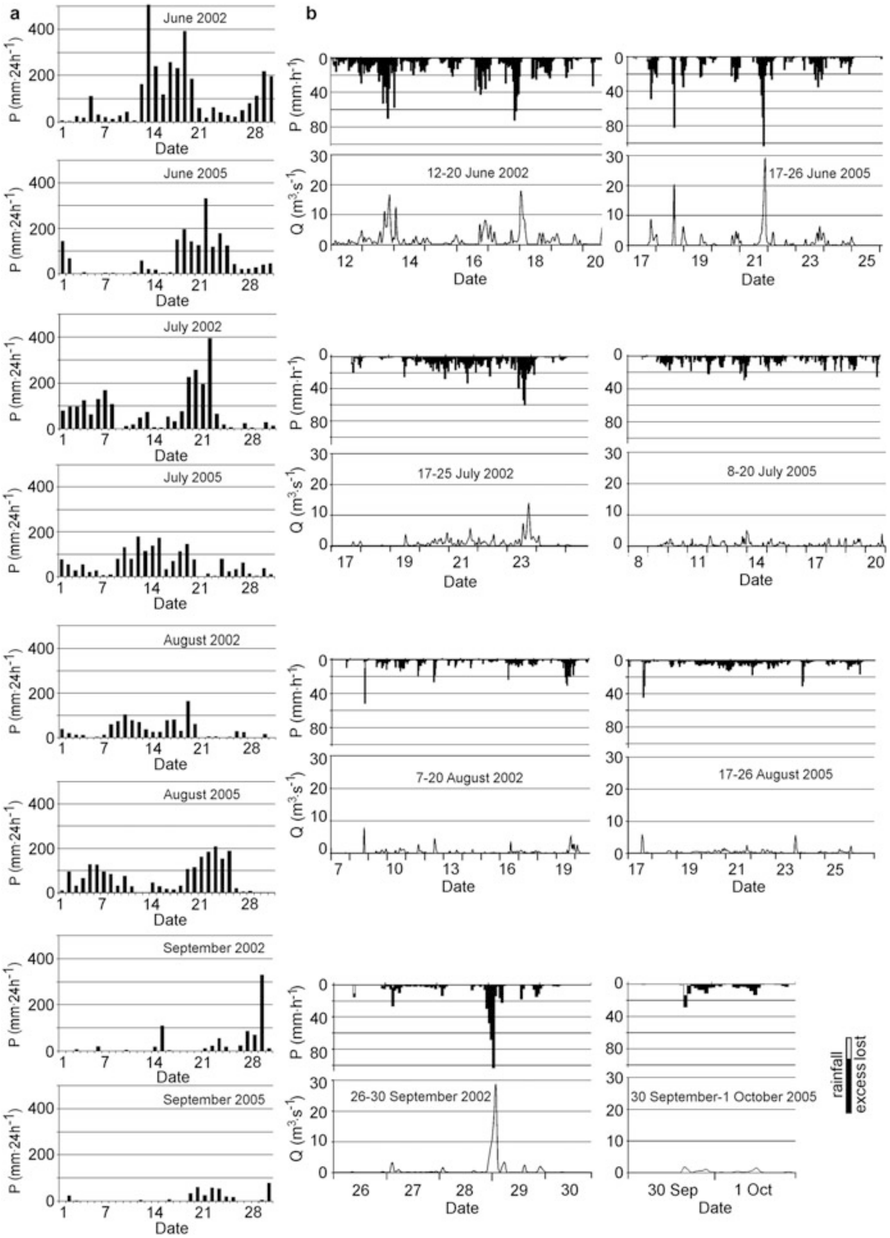

Fig. 10.3 Hydrological response of the Maw-Ki-Syiem catchment to the highest rainfall during the monsoon seasons in 2002 and 2005, (**a**) daily rainfall, (**b**) hydrological response of the catchment to the highest rainfall, P rainfall, Q flow

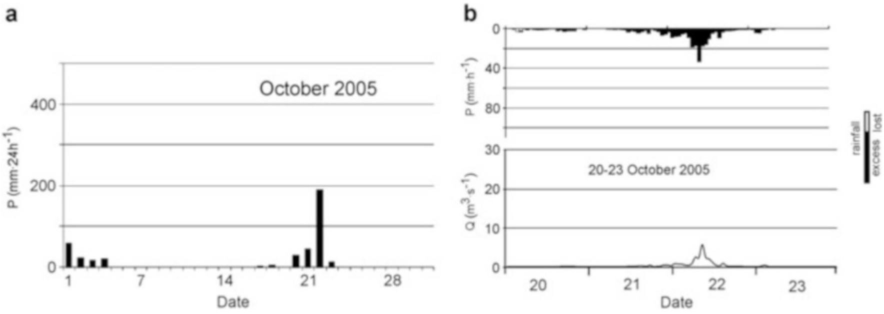

Fig. 10.4 Hydrological response of the Maw-Ki-Syiem catchment to the highest rainfall in October 2005, (**a**) daily rainfall, (**b**) hydrological response of the catchment to the highest rainfall, P rainfall, Q flow

Hydrographs produced for recorded rainfall events in the Maw-Ki-Syiem catchment in the pre-monsoon, monsoon, and post-monsoon seasons, revealed a rapid response of the catchment to heavy rainfall. The rising limb and recession limb are very steep and coincide with hourly rainfall patterns. It is notable that the hydrological response of the catchment is approximately of linear-type. The fast response of the catchment may be explained by its small dimensions (0.22 km^2) and small retention capacity, both of which favor overland flow. The predominant role of these two factors was also emphasized by Starkel et al. (2002); Froehlich et al. (2003); Froehlich (2004) and Soja et al. (2004). Hourly rainfall, recorded during rainy periods, was usually less than 20 mm, regardless of the season. This precipitation generated flood waves with the following parameters: $Qmax < 2.5\ m^3\ s^{-1}$ and $qmax < 11\ m^3\ s^{-1}\ km^{-2}$. However, flood events with maximum flow exceeding 20 $m^3\ s^{-1}$ ($qmax > 90\ m^3\ s^{-1}\ km^{-2}$) were recorded both during pre-monsoon and monsoon seasons. The highest flow peaks, observed on hydrographs, ranged from 22.2 $m^3\ s^{-1}$ (pre-monsoon) to 27.8 $m^3\ s^{-1}$ (monsoon), and were generated by rainfall exceeding 100 mm h^{-1}.

10.4.5 Relationship Between Rainfall, Maximum Flow and Maximum Specific Flow in the Maw-Ki-Syiem Catchment

The relationship between maximum flow (Qmax) and rainfall intensity (P) is shown on the log-log plot (Fig. 10.5a). The statistical relationship is described by an exponential-type equation: $Qmax = 0.0347P^{1.4649}$ ($R^2 = 0.982$; $p = 0.05$). For maximum specific flow (qmax), this relationship is described by the same type of equation with the following parameters: $qmax = 0.1578P^{1.4649}$ ($R^2 = 0.982$; $p = 0.05$).

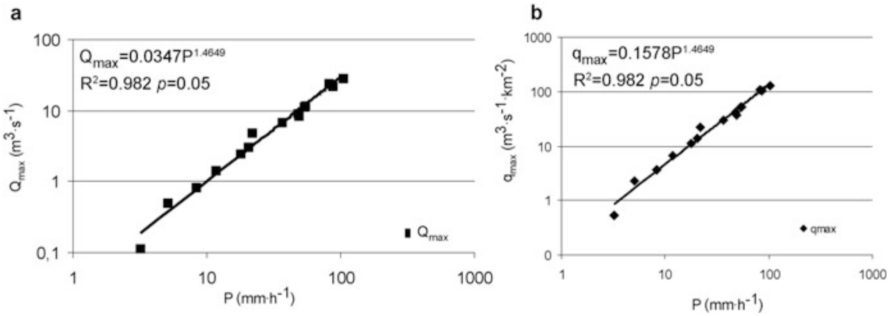

Fig. 10.5 Relationship between rainfall, maximum flow and maximum specific flow in the Maw-Ki-Syiem catchment, (**a**) maximum flow (Qmax) and hourly rainfall (P), (**b**) maximum specific flow (qmax) and hourly rainfall (P)

These statistical relationships may be considered "envelope curves" describing maximum flow and maximum specific flow in the Maw-Ki-Syiem catchment. However, these relationships may support the estimation of these parameters in small, ungauged catchments near the town of Cherrapunjee in India, on the basis of rainfall data, which are easily accessible for this region.

10.4.6 Magnitude of Flood Waves in Maw-Ki-Syiem Versus World Records

The climate conditions and environmental setting of the Cherrapunjee region suggest that the hydrological response of a catchment should be comparable with the highest values reported throughout the world.

Maximum flow for the Maw-Ki-Syiem catchment was calculated to be 27.8 $m^3\ s^{-1}$ and it is about 1 $m^3\ s^{-1}$ smaller than the value calculated via the Herschy (2002) formula, which describes the highest values of maximum flow throughout the world.

An overview of the top ten flash flood events in the world (Rodier and Roche 1984; Costa 1987) where the highest values of maximum specific flow have been noted, reveals the highest rank of the Maw-Ki-Syiem catchment (Table 10.2). Most maximum specific flows have been reported for local flash flood events in catchments with an area larger than 1.7 km^2. The area of the Maw-Ki-Syiem catchment is smaller (0.2 km^2) and there is lack of data for such small catchments. Therefore, the comparison is not direct. The differences are not large. The value calculated for the Maw-Ki-Syiem is only about 18 % higher than the value reported for a Humbolt River tributary near the town of Rye Patch in Nevada in the United States.

Maximum specific flow, calculated on the basis of an equation ($qmax = 350A^{-0.4}$) describing the highest values of this parameter in the world, reached 641 $m^3\ s^{-1}\ km^{-2}$ and was several times higher than the highest value

Table 10.2 Maximum specific flow recorded throughout the world and related *K* indexes

Name	Country	A (km^2)	Date	Qmax ($m^3 s^{-1}$)	qmax ($m^3 s^{-1} km^{-2}$)	*K* (−)
Zita	Tunisia	3.5	12.12.1976	131	37	4.8
Soldier Creek	USA	5.34	05.10.1970	201	38	4.9
Ribeira Brava	República de Cabo Verde	6.7	26.09.1976	253	38	5.0
Bronco Creek near Wikieup (Arizona)	USA	49.2	18.01.1975	2080	42.3	5.7
Meyers Canyon near Mitchell (Oregon)	USA	32.9	27.07.1965	1540	46.8	5.7
Riviere Blanche	Martinique	4.3	20.08.1970	210	49	5.0
Halawa Stream	USA	12	02.04.1965	762	63.5	5.5
Honopou Stream	USA	1.7	18.11.1930	162	95.3	5.1
Humbolt River tributary near Rye Patch (Nevada)	USA	2.2	31.05.1973	251	114.1	5.3
Maw-Ki-Syiem	India	0.2	22.06.2005	27.8	139.0	4.8

Source: This study on the basis of Rodier and Roche (1984) and Costa (1987), *A* catchment area, Qmax maximum flow, qmax maximum specific flow, *K* flood index (Françou and Rodier 1969)

recorded until now (Table 10.2). It seems that this value is not possible to obtain, even in one of the rainiest areas of the world. The differences between calculated and measured maximum specific flow may result from a lack of hydrological data for small catchments. The position of the envelope curve characterizing the maximum specific flow (equation mentioned above) was determined using hydrological data obtained for catchments larger than 100 km^2 (Gaume et al. 2009). The reduced exponent in this equation (−0.4), for smaller catchments, should be revised in the context of this study.

The index *K* allows to compare the magnitude of a flood wave regardless of catchment area. Therefore, it may be considered a better measure for comparison purposes. The highest values of the *K* index calculated for extreme flash flood events exceeded or were close to 5 (Table 10.2). In the case of the Maw-Ki-Syiem catchment, the value of index *K* was a little lower than the values recorded in other regions of the world.

10.5 Conclusions

The Cherrapunjee region in northeast India is known as a place with some of the highest amounts of rainfall in the world. This top position is related to long-lasting rainfall and annual records (Dhar and Farooqui 1973; Cerveny et al. 2007). Cherrapunjee holds the world's rainfall record for durations from 15 days to 2 years (Rakhecha and Singh 1999). In terms of hydrological consequences, this level of precipitation may generate large floods across the Bengal Plain (Monirul Qader Mirza 2003). In this sense, the Cherrapunjee region produces a strong impact on flood stages across large parts of northeast India and Bangladesh.

The hydrological response of stream catchments across the Meghalaya Plateau near Cherrapunjee is determined mainly by short-duration rainfall events. The hydrological response of each catchment in the region is closely related to hourly rainfall. This may be explained by low retention capacity of a catchment. As a result, precipitation is converted into excess rainfall and saturated overland flow contributes to runoff formation, regardless of the season of the year. In addition, it is notable that fully saturated soil was reported during the late post-monsoon season (Froehlich 2004). Hydrographs developed for the Maw-Ki-Syiem catchment have steep rising and recession limbs and follow hourly rainfall patterns. Hourly rainfall was usually less then 20 mm, regardless of the season. This precipitation generated flood waves with the following parameters: Qmax < 2.5 $m^3 s^{-1}$ and qmax <11 $m^3 s^{-1} km^{-2}$. Precipitation higher than 80 mm h^{-1}, resulted in a maximum flow peak higher than 20 $m^3 s^{-1}$ and maximum specific flow exceeding 90 $m^3 s^{-1} km^{-2}$. These events may occur both during the pre-monsoon and monsoon seasons and induce local flash flooding. The highest flow peaks, observed on hydrographs, ranged from 22.2 $m^3 s^{-1}$ (pre-monsoon) to 27.8 $m^3 s^{-1}$ (monsoon). The peaks were generated by rainfall exceeding 100 mm h^{-1}. It is notable that the runoff coefficient was close to 1 during these intense rainfall events (Bryndal et al. 2015), meaning that all rainfall is converted into runoff. This is important, as far as the influence of the Cherrapunjee region on flood formation in neighboring regions, especially the Bengal Plain is concerned.

Maximum specific flow in the Maw-Ki-Syiem catchment is one of the highest in the world. Calculations based on the envelope curve developed by Herschy (2002), which describe flow maxima for catchments smaller than 100 km^2, and top 10 maximum specific flows, indicate that Qmax – 27.8 $m^3 s^{-1}$ and qmax 139 $m^3 s^{-1} km^{-2}$ are feasible. Similar conclusions may be drawn on the basis of the *K* index, which allows for a comparison of flood magnitudes regardless of catchment area. In this regard, the equation ($q_{max} = 350A^{-0.4}$) describing the highest values of this parameter in the world, significantly overestimates maximum specific flow in very small catchments. Therefore, the reduced exponent in this equation (−0.4) should be revised.

The relationship between rainfall intensity versus maximum flow as well as rainfall intensity versus maximum specific flow, as defined in this study, may support the estimation of maximum flow and maximum specific flow on the basis of rainfall data (readily available for this region) in small ungauged catchments near the town of Cherrapunjee.

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Chapter 11
Altitudinal Zonation of Floral Biodiversity and Its Conservation Pattern in Mizoram, North-East India

Vishwambhar Prasad Sati and Lalrinpuia Vangchhia

Abstract This paper examines altitudinal zonation of floral biodiversity and its conservation patterns in Mizoram, North-East India. Floral biodiversity in Mizoram is tremendously high in the forms of forests – tropical, montane and temperate; grasses and bamboo forests. Out of the total geographical area, 19,240 (91.3 %) land is under vegetation cover and about 75 % land is forest cover. The state of Mizoram is located in the eastern extension of the Himalaya and it is one amongst the biodiversity hotspots of the world. Floral biodiversity vary according to altitudinal zones and the amount of rainfall, from tropical evergreen forest to montane and temperate forest. Forest products are the second major sources of livelihood, as a large number of people are dependent on them. Forests are conserved by the local people through traditional knowledge. As a result of this even, the whole country received decrease in forestland; Mizoram has registered about 1.4 % increase during the last three decades. Data were mainly gathered from the secondary sources, largely from the India State Forest Report (ISFR) 1991, 2001 and 2011. Similarly, data from the Department of Environment and Forest, Government of Mizoram on forest diversity and their distribution pattern were also collected. Further, wide range of discussion was made with the officials working in the forest department and with the local people to elaborate the other aspects of forest resources such as use pattern of forest products and their conservation pattern. Personal observation on forest diversity use pattern and their conservation was also carried out after rapid field visits.

Keywords Floral biodiversity • Conservation • Altitudinal zones • Climate • Rainfall • Mizoram

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11.1 Introduction

India obtains great altitudinal variations, diverse soil types and varying climatic conditions with rainfall variations, have been blessed with sixteen forest types ranging from tropical rainforests to dry thorn forests based on species composition and plant functional types (Champion and Seth 1968). Mizoram, the eastern extension of the Himalaya is considered as one of the global biodiversity hotspots (Myers et al. 2000) with varied climate ranging from humid tropical to sub-alpine type (Roy and Joshi 2002). It is known for obtaining high ethnic and biological diversity and occupied part of the Indo-Burma biodiversity hotspots (Myers et al. 2000). They obtain some of the largest reserves of tropical and sub-tropical forests of wet evergreen, semi – evergreen, moist deciduous, coniferous forests, mixed forest and shrub land (Globcover 2008; Roy and Joshi 2002). The state of Mizoram has high floral biodiversity and it is distributed according to an altitude and the amount of rainfall from tropical evergreen to montane and temperate forests.

Climatic factors mainly rainfall influence the floral diversity. Several studies related to vegetation-climatic factors (rainfall) have been extensively documented in arid and semi-arid environments, there has been relatively limited research on such a link between vegetation activity and rainfall in high precipitation belts of the world, for instance the eastern extension of Himalaya (Prasad et al. 2005, 2007; Saikia 2009). The tropical forests are the least water stressed regions due to heavy rainfall (Malhi and Wright 2004). Here, the rainfall trend follows an uneven and continuity throughout the year. The longest wettest period between May and September was witnessed during 1990–2000 (Prasad et al. 2005).

Mizoram, literary known as the 'land of highlanders' lies in the eastern extension of the Himalaya, as a part of Arakan-Yoma mountain ranges of Myanmar. Its international boundary is delimited by Bangladesh in the west and Myanmar in the east and south. It obtains 21,087 km^2 area and shares 0.64 % of the country's geographical area. The state lies between 21° 56′ N – 24° 31′ N and 92° 16′ E – 93° 26′ E. The average altitude ranges from 500 to 800 m with the maximum elevation 2157 m is found in Blue Mountain (Phawngpui) (FSI, 2011). Climatic conditions vary from the moist tropical to the moist sub-tropical, not very warm in the summer season and not very cold in the winter season. During the winter, the temperature varies from 09 °C to 18 °C and in summer, it varies between 18 °C and 30 °C. Presence of regular monsoon tremendously influences the climatic conditions. Heavy downpour occurs during the monsoon season from May to September and the average annual rainfall ranges from 2160 to 3500 mm. The high velocity of wind, characterized by turbulence storms blow during the 2 months of March and April. The direction of winds is cyclonic and the monsoon rain is also characterized by cyclones. The winters in Mizoram are normally rain free and sky remains almost clear during the 4 months – November, December, January and February. High rainfall and moist climate leads to rich biodiversity consequently the total land under vegetation is 91.3 % while, the actual forest cover is about 75 %. Forest is a lifeline of the populace of Mizoram as the large numbers of people are directly dependent on forest products for running their livelihoods (Sati 2013a). Agriculture, dominated by shifting cultivation, runs parallel and constitutes a major source of livelihoods. It covers about 50 % area of the total sown area (4.5 %). Industrially, this state is lagging behind as there are no major industries established till now. Forest based industries have the high potentials. Tourism may be the important industry as climatic conditions are very feasible throughout the year. Further, the panoramic landscape and evergreen forest are quite attractive and they will accelerate the tourism practices (Sati 2013b). The population of the state was 1.09 million (Census 2011) which constituted 0.09 % of the country's population. Of this, rural population was 48.49 % and urban population was 51.51 %. The population density was 52 persons per km^2. The livestock population of the state was 0.33 million (Livestock Census 2007). This paper examines the floral biodiversity, its altitudinal distribution, uses and conservation pattern in Mizoram state.

11.2 Altitudinal Zonation of Floral Biodiversity

The floral biodiversity of Mizoram state is divided into four altitudinal zones. Mostly altitude and rainfall determines the forest types as Singh et al. (2002) observed that floral biodiversity in Mizoram are found according to altitude, rainfall and dominant species composition. Although, there is no specific boundary in the forest types rather, there are mixed forest, grown in all the altitudinal zones. Floral biodiversity is characterized mainly by the presence of tropical rain forests; as most of the part of the state lies in the tropical regime. Meanwhile, montane and temperate forests are also found between 1100 and 2100 m. Bamboo forest is extended between 400 to 1500 m. Table 11.1 depicts altitudinal zones, forest types, forestland/density (in km^2), total forest land and per cent of total forest area. Details are given as follows.

11.2.1 Zone: I

This zone is located <500 m, covers 8605 km^2 (44.72 %) areas, which has the highest forest area. There are more than 98 number of forest species. The main forest areas are (Sawmliana 2003): *Hnahpawl, (Calotropics gigantean), Leihruisen (Calycopteris flribunda), Zo archhuang (Celosia argentea fa cristata), Leihruisen (combretum flagrocarpum), Vai mau (Dendrocalamus giganteus), Lawi thing (Acacia catechu), Thing-thei-hmu-par (Acalypha indica), Kum-za-pal/Sai-dai (Agave Americana), Kep tum (Crinum asiaticum), Nu beng chah (Cyperus scariosus), hakawk (Sc – Diplazium maxima), Tuipui sut hlah (Homonoia riparia), Ui te me (Mucuna pruriens), Hnai bung (Palaquium polyanthum), Ram lakhuih (Pandanus*

Table 11.1 Characteristic of floral biodiversity in different altitudinal zones

Altitudinal zones	Altitude (in M)	Types of forest/number of species	Forestland/density (in km^2)			Total forest area (in km^2)	% of total forest area
			Very dense	Moderately dense	Open forest		
Zone I	<500	Tropical wet evergreen forest mainly comprised of open scrub and small trees/98	1	1,813	6,791	8,605	44.7
Zone II	501–1,000	Tropical wet evergreen forest mainly comprised of open to moderate with moderately tall tree/444	34	2,921	4,520	7,475	38.9
Zone III	1,001–2,000	Sub-tropical montane forests comprised of open to moderate, mainly big and tall tree/500	98	1,516	1,544	3,158	16.4
Zone IV	>2,000	Temperate evergreen forest comprised of very dense, big and tall trees/50	1	1	0	2	0.01
TOTAL		1,092 species	134	6,251	12,855	19,240	91.3

Source: Statistical handbook, Environment & Forest department, Govt. of Mizoram, 2011

fascicularis), Tu bal (Rhaphidophora decursiva), Tui pui len hmui (Syzygium polypetalum), Re raw (Terminalia citrine), Thing dawl (Tetrameles nudiflora) and Hrui ri thet (Tetrastigma bracteolatum). Out of the forest area, the highest area is in under open forest, followed by moderate forest, and dense forest obtains very less area (1 km^2).

11.2.2 Zone: II

This zone is located between 501 and 1000 m elevation. The total area under forest is 7475 km^2 (38.85 %). About 444 forest species are found in this zone and out of it, the most common species are *Nim thing (Azadirachta indica), Pangkai (Lutqua or Bhooby) hriang (Bentula alnoides), Phunchawng (Bombax ceiba), Thepalingkawh*

(Bruinsmia polysperma), Nauban (Bulbophyllum lobbii), Thil te (Calamus tenius), Theikhuangchawm (Choerospondias axillaris), Tlangsam (Chromolaena odorata), Saper Bul (Cinnamomun glaucescens), Khum (dalbergia lanceolaria), April par (Delonix regia), Zuang (duabanga grandiflora), Naufa (Embelia ribes), Sun – hlu (Emblic myrobalan), Fartuah (Erythrina variegate), Laisua (Licuala peltata), Herhse (Meaua ferrea), Lawi-thing (Acacia catechu) Khang-ngo (Acacia Oxyphylla) and Thei Arbawm (Annona squamosa). The highest area is covered by open forest (4575 km^2), which is seconded by moderately dense forest (2921 km^2), while dense forest obtains only 34 km^2.

11.2.3 Zone: III

This zone is located between 1001 and 2000 m, covering an area of 3158 km^2, which represents 16.41 %. The forest is characterized mainly by moderately dense and open forests. Out of the total forest area, 48.89 % area is under open forest, which is followed by moderate forest (48 %) while dense forest covers only 3.1 %. There are more than 500 different forest species and among them the most common species are: Vaube (Mountain ebony or Camel's foot tree), *Hriang (Betula alnoides), Khuangthli (Bischofia javanica), Punchawng (Bombax seiba), Hruipui (Calamus erectus), Tum (Caryota urens), Sehawr (Castanopis indica), ThingSia (Castanopsis tribuloides), Sazuk thei (Catunaregam spinosa), Tu far or Lehngo far (Cephalotaxus griffithii), Thei kelki suak (Wax leaved climber), Vawm bal (Drimycarpus racemosus) Hnum (Engelhardtia spicata), Hmawng (Ficus religiosa), Aiting (Mantisia spathulata), Chang el (Musa paradisiacal var sylvestris), Keifang (Myrica esculenta), Bul fek (Phhoebe lanceolata), Far (Pinus kesiya) Tlaizawng (Prunus cerasoides) and Thainu rual (Pavetta indica).*

11.2.4 Zone: IV

This zone is located about 2000 m, comprises only 2 km^2 and has more than 50 different big plant species. Dense to moderate forest mainly characterizes this zone, which covers 50 % forest area and rest of 50 % is open forest. The common forest species are: *Lallai (Camellia kisssi), Silver Oak (Grevillea robusta), Tlangnal/Par uih (Gynura bicolor), Zawng a tuikhur (Lady's slipper), Chhawkhlei par sen (Rhododendron arboretum), Chhawklei par var (Rhododendron Parryae), Raw ngal. (Schizostachyum fuchsianum) and Far. E – Khasi pine (Pinus kesiya).*

11.3 Bamboo Forest

Mizoram has abundant natural bamboo forest resources as bamboo covers about 57 % of the total geographical area, ranging from 400 to 1500 m (mostly between zone 2 and 3). There are 27 species of bamboos found in Mizoram. The most common species are: (1) *Mau tak (Melocanna baccifera)* is found up to 1000 m elevation, is used for building, paper pulp, furniture and also for making house wall, thatching, mats, baskets etc. Tender shoots are used in curries and pickles, (2) *Phulrua (Dendrocalamus hamiltoni)* is largely found between 600 and 1200 m, is used for temporary building, mats, baskets, gutters, water vessels and fire, (3) *Raw pui or Vai mau (Dendrocalamus giganteus)* is found an altitude of 500–1200 m is used for building construction. The young shoots are used as vegetable curries, (4) *Vai rua (Bambusa bambos)* is extended up to 1000 m, is extensively used for building construction, rafters, house posts, tent poles, mats, baskets and fire, (5) *Raw nal (Dendrocalamus longispathus)* is found up to 1000 m, culms are used for building construction, baskets etc. and the young shoots are cooked as vegetable curries and culms are used to make paper pulp.

11.4 Use Pattern of Forest Products

Timber and non-timber forest products are extensively used in Mizoram. They are the most important source of income and livelihoods after agriculture. Roots, stems and leafs have diverse use from medicine to construction of houses. The uses of major forest products are as follows: Woods of *Khuangthli* and fur are used for constructing building, house posts, bridge and making furniture. Its fruits are nutritious and a source of food. Fur resin produces high quality of turpentine. The culms of *Raw nal* is used for making baskets, hats, blow guns, tying fence, fire and households' materials. *Thingsia* is used for Posts, charcoal, firewood and building house. Its nut is highly valuable and used as dry fruits. It is also useful for feeding animals. *Lallai* wood is used for making fence posts, handle tool and firewood. The cane of *Hruipui* is used for making chairs, baskets, hats, container and other household's materials. *Tlangsam* has medicinal value. Juice of it leafs is used to cure injuries. *Thilte* is used for making basket, mats, furniture and chair seats. It top shoots cure dysentery. It leaves substitute tea. *Nim thing* is used for making furniture, drums, houses, boats and also used fuel wood for cooking. Bark, leaves and fruits are used as medicine. It leaves are used as fodder to feed goats, sheep, camels and wild animals. *Thingdawl* is another valuable tree which is used for making floor, wall, matches and packing cases. Its bark is poisonous. The leaves of *Kep tum* are used as vegetable leafs; tuber and leaves are also used as medicine. *Kumza Pal* or *Sai Dai* is used for fencing and medicine. It also yields excellent fiber which suited for ropes and cordage. The bark of *Hnahpawl* yields a fiber which is used for making fishing nets and bow strings. The floss is used for stuffing cushions and pillows. Its wood makes gun powder and charcoal. The root, bark, leaves and buds are also used as medicine. The flowers of *Zo Archhuang* are useful medicine that control diarrhea and in excessive menstrual discharge. It seeds are used to control pain, cough and dysentery.

11.5 District-Wise Distribution of Forests

The forest cover in the state, based on interpretation of satellite data of January 2009 (FSI, 2009), was 19,240 km^2, which was 91.3 % of the state's geographical area. The data of 2011 supports this number. Out of the total forest cover, protected area was 1240.75 km^2 which was 5.88 % of the total geographical area. In terms of forest canopy density classes, the state has 134 km^2 area under dense forests, 6209 km^2 area under moderately dense forests and 12,897 km^2 area under open forests. Table 11.2 presents district wise forest cover in km^2. It further reveals nature of forest cover i.e., very dense forest (VDF), moderate dense forest (MDF), open forest (OF) and percent of geographical area. Lunglei Lawngtlai and Saiha districts cover highest forest area (and 92.7, 92.6 and 92.2 % respectively) followed by Mamit (91.7 %) and Aizawl districts (91.3 %). In terms of the forest cover change during the last two decades, 1.4 % increase was registered in Mizoram state.

Protected areas, in the forms of national parks and wildlife sanctuaries, covered 1240.75 km^2 which was 5.88 % of the total geographical area (2011). There are three national parks and seven wildlife sanctuaries spread in seven districts of state. The first tiger reserve Dampa was established in 1994 is the first and the biggest (500 km^2) national park located in Mamit district. The area of national parks and wildlife sanctuaries varies from 35 to 500 km^2. Table 11.3 reveals national parks and wildlife sanctuaries of Mizoram state.

Table 11.2 District-wise distribution of forests (area in km^2)

District	Geographical area	VDF	MDF	OF	Total	Per cent of GA
Aizawl	3575	26	1205	2034	3265	91.3
Champhai	3185	57	1096	1632	2785	87.4
Kolasib	1382	0	197	1046	1243	89.9
Lawngtlai	2557	0	705	1664	2369	92.6
Lunglei	4536	1	1233	2972	4206	92.7
Mamit	3025	45	697	2032	2774	91.7
Saiha	1400	0	568	723	1291	92.2
Serchhip	1421	5	508	794	1307	91.9
Total	21,081	134	6209	12,897	19,240	91.3

Source*:* FSI (2011), Sati et al. (2014)

Table 11.3 National parks and wildlife sanctuaries

S. no.	Name of protected areas	Area in km^2	District	Establishment year
1	Dampa Tiger Reserve	500	Mamit	1994
2	Murlen National Park	100	Champhai	2003
3	Phawngpui National Park	50	Lawngtlai	1997
4	Ngengpui Wildlife Sanctuary	110	Lawngtlai	1997
5	Khawnglung Wildlife Sanctuary	35.75	Lunglei	2000
6	Lengteng Wildlife Sanctuary	60	Champhai	2002
7	Tawi Wildlife Sanctuary	35	Aizawl	2001
8	Thorangtlang Wildlife Sanctuary	50	Lunglei	2002
9	Pualreng Wildlife Sanctuary	50	Kolasib	2004
10	Tokalo Wildlife Sanctuary	250	Saiha	2007

Source: DoEF, GoM (2012), Sati et al. (2014)

11.6 Conservation Pattern of Floral Biodiversity

In Mizoram state, forest resource management has been carried on by the two institutions – the forest department (state owned) and community people. About 66 % forest land is directly under the state forest department. The state forest department is structured from the state level to the village level where the department meets the various needs of the local people and also implements the rules related to forest conservation. The state government Forest Act of 1955 has framed and implemented rules to conserve forest. Under this act, the state government notified 16 riverine reserved forests, covers 1832.50 km^2. Further, 570 km^2 forest area was also notified as the inner-line reserved forest. Roadside reserved forest covers 97.20 km^2 areas. There are 23 others reserved forest that cover 1873.65 km^2. State, districts, towns and villages equally contribute to forest conservation. In addition, the state government identified three compensatory afforestation areas of 30.86 km^2.

Forest resource management is practiced in different forms in Mizoram. Community forests are conserved by the local people based on the principles of providing opportunities for extraction of goods for legitimate needs and ensuring the continued existence of forest resources for future (Chatterjee *et al.*2000). The extent of forests under community control in Mizoram was 31.35 % (FSI 2009). There is great variability in management practice, which has evolved under different biophysical and cultural environments (Nongkynrih 2001). However, scientific research on the forest management practices of traditional and tribal societies is lagging behind but a few studies have investigated that sacred grove, home gardens and agro-forestry is practiced here scientifically (Tiwari and Shahi 1995; Tiwari et al. 1998).

Role of the community people towards forest management is also noteworthy as the community people owned about one/third forest area for their different households need. According to Tiwari et al. (2013a), traditional forest management in Mizoram was administered by the ‘chieftain’. The Chief is called ‘*Lal*’ (now 'chairman' Act of 1956) had absolute decision-making authority. There is pyramidal structure of the village office bearers; those are involved in the management of forest. The councilor and youth commander (Val Upa) are the members of the council and the council is responsible to Village Assembly. This traditional institution is no longer existed and it has taken over by the Young Mizo Association. The new organization is doing so promptly towards management of forests.

The conservation of forest in Mizoram is very peculiar (Tiwari et al. (2013b). There are two forest areas in the surrounding of village. In the one forest area, the villager can go and collect the forest products and in the other forest area nobody can go insight and nothing can be taken outside without the permission of the conservators. These forest protected areas are called 'closures' in Africa (Sati 2007). All these traditional concepts are practiced today. The community people have created recreational forests and village reserved forest where from they can collect the forest products.

The state government has launched several programmes to conserve forests during the past. To protect forest from fire, especially during the period of lashing and burning of forest for shifting cultivation, the state government has fixed time for burning of *jhum* land, depending upon weather condition/year. Generally, this period is fixed from first week of February to 15th March every year. The farmers are asked to complete clearing, lashing and burning the *jhum* land before 15th March. This process is nomenclature as 'Meilam Sah', means to protect forest from excessive fire due to burning of *jhum* land for shifting cultivation.

The second programme is forest conservation awareness in the villages. Every year, three villages that contribute towards forest conservation are awarded by the government. Token money and a certificate are given for their contribution. Similarly, the top three newspapers and magazine are awarded for their contribution in the field of forest conservation. The State has also a provision to fine the villages, which are unable to follow the existing rules of forest conservation. These rules are yet to be implemented thoroughly. Efforts are on the full swing to reduce the practices of shifting cultivation and *jhum* lands and the State is giving emphasis to terraced and wet rice cultivation. The state government launched 'New Land Use Polity' has the objective to transfer the land from shifting cultivation to cultivation of horticulture, silviculture, sericulture, fishing and animal husbandry.

The practice of 'Meilam Sah' is common. Earlier, the rural people conserved the forest to reuse forest land for shifting cultivation. Recently, the rural people realized that the conservation of forest is necessary not only to utilize them for the shifting cultivation but also because to increase the environmental quality. The Non Government Organization such as the Young Mizo Association plays a vital role in conservation of forests in Mizoram state. These organizations performed various awareness programmes through educating people and imparting training to prevent forest fire. Due to this policy, the forest land of the State has been increased by 1.4 %.

11.7 Conclusions

In this paper, floral biodiversity, its altitudinal zonation and conservation pattern in Mizoram state was illustrated extensively. The discussions on floral diversity reveals that the state of Mizoram has hundreds of floral species from tropical evergreen wet to montane and temperate evergreen species that are distributed from <500 to >2000 m. Bamboo is also extensively grown. The high floral biodiversity in Mizoram state has enhanced the environment quality thus; the Environmental Sustainability Index of the state is 80–100 %, which is the highest level at national and international levels. Floral biodiversity is maintained by high rainfall throughout year. This study further reveals that the forest and forest products are highly valuable, have multiple uses and these products are the major sources of livelihood sustainability. The role of the State and community people in conservation of forests is significant. Meanwhile, forest degradation is high mainly due to shifting cultivation. The landscape of Mizoram is precipitous, rough and rugged and forest areas area remotely located thus, most of the dense forest areas are unused. The situation of over and under use of the forest resources maintain the forestland. The trend of shifting cultivation has been decreased as the marginal farmers are adopting permanent cultivation and it is supported by the governmental policies. This has also led to increase in forest land. This study suggests that changes in the shifting cultivation will further increase forest cover. Optimum use of forest resources will enhance the livelihoods of the rural poor people as they are fully dependent on forest products. This will be possible only if the remotely located dense forest areas are accessed. Further, sustainable use of timber and non-timber forest products that include Bamboo shoots, jack fruits, pineapples, medicinal plants (all grow wild) can enhance livelihoods as these products are grown extensively in Mizoram state and they have a greater role in economic development of the region.

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Chapter 12
The Distribution and Management of Forests in Arunachal Pradesh, India

Kazuharu Mizuno

Abstract The State of Arunachal Pradesh is located in the northeastern part of India, surrounded by the borders of Assam, Bhutan, and Tibet (China). There has been a long history of conflict over the sovereignty of this area between India and China. Foreigners were prohibited from entering the state until the 1990s and, therefore, the area has been veiled in secrecy until recently. The Monpa people, who reside in the western region, have historically deep ties with Tibet and the Tibetan Buddhist faith.

Inhabitants of the Dirang area, West Kameng District of this state, categorize forests into three types: *Soeba shing*: forests to pick up fallen leaves; *Borong*: forests to gather fuel wood; and *Moon*: forests for gathering timber and hunting. Each type of forest is managed accordingly. Fallen oak-tree leaves are collected from *Soeba shing* around villages and spread over agricultural fields as fertilizer for barley and buckwheat, which are produced as subsidiary crops of maize, or as a mulch to inhibit weeds or to stop soil erosion in the rainy season. *Soeba shing* are controlled to form pure forests of oak trees by weeding out any needleleaf trees. Fallen leaves are gathered from one's own land. No one, not even the owner, is allowed to cut down any live oak tree. Some *Borong* forests are communally owned by clans, and others are privately owned by individuals. *Moon* forests belong entirely to clans as common property. People belonging to a clan have the right to acquire necessary resources from *Borong* or *Moon* forests that their clan owns. Illegal logging has recently become common, and the price of timber continues to rise. Local residents of these areas have begun to take action for forest conservation.

Keywords Arunachal Pradesh • Forest distribution • Fallen leaves • Timber use • Assam Himalaya

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Fig. 12.1 Location of the state of Arunachal Pradesh

12.1 Distribution of Forests

The 24th state, Arunachal Pradesh, has been part of India since 1914, when the McMahon Line agreement between Tibet and the British Indian government at Simla was signed.

The state of Arunachal Pradesh is located in the northeastern part of India, to the north of Assam State, east of Bhutan, and south of Tibet (Fig. 12.1). There has been a long history of conflict over ownership of this area between India and China. Entry of foreigners into this state was prohibited until the 1990s; thus, the area has been veiled in secrecy until recently. Even today, special permission and an approved guide as escort are obligatory for foreigners wishing to enter this area.

Between 22 and 24 (51, if subdivisions are considered) ethnic groups are distributed in the state of Arunachal Pradesh. The Monpa people, found in its northwestern part, are a Tibetan ethnic population, having historically deep ties with Tibet and the Tibetan Buddhist faith; religious temples are common in the area.

The average annual amount of precipitation is approximately 1000 mm at Dirang around 1700 m above sea level (Kri 2010). The annual mean maximum temperature at Bomdila (2430–2700 m above sea level) is 20.8 °C, and the annual mean minimum temperature is 6.0 °C (Gopalakrishanan 1994).

The temperate forests in Dirang valley, Tawang valley, and Kalaktang valley located 1500–3000 m above sea level, are composed primarily of *Rhododendron* *arboreum*, *Quercus griffithii*, *Alunus nepalensis*, *Populus ciliate*, *Lyonia ovalifolia*, and conifer trees such as *Pinus wallichiana*, *Taxus baccata*, and *Tsuga dumosa* (Choudhury 1996). Sub-alpine vegetation is found in hill slopes 3000–4000 m above sea level. These are composed of conifer trees, such as *Abies densa*, *Abies spectabilis*, *Tsuga dumosa*, and *Larix griffithiana* and of small *Rhododendron*, *Berberis*, *Rosa*, *Cotoneaster*, and other trees. The forest line is approximately 4000 m above sea level. Forests around the line consist of shrubby fir trees, and alpine plants become prevalent above it. Herbaceous species including *Anemone*, *Primula*, *Potentilla*, *Pedicularis*, *Cassiope*, *Aconitum*, and so on, dominate the alpine zone, which is more than 4000 m above sea level.

A total of 1300 species of orchid have been reported in India, and about 600 are found in the northeastern region (Choudhury 1996). More than 76 species belonging to 65 genera with known medical uses have been collected in this area. The starchy corms of *Fritillaria cerrhosa*, known as *Yathu*, are considered to be of great medicinal value by the local people. People apply the crushed paste of the corms to relieve acute muscular pain (Choudhury 1996). Species such as *Berberis aristata*, *Coriaria nepalensis*, *Symplocos theaefolia*, *Geranium nepalensis*, *Rubia cordifolia*, *Englhardtia spikata*, *Taxus baccata*, *Gallium mullugo*, *G. triflorum*, and so on, are used for dyeing and tanning. The roots of *Valeriana hardwiekii* and *V. wallichii* produce perfumes (Choudhury 1996).

Large parts of the forested areas in Arunachal Pradesh belong to clans, villages, and individuals. National parks comprise 4.79 % (2468.24 km^2) of the forested area, and 13.70 % (7059.75 km^2) belongs to wildlife sanctuaries. Protected forests and reserved forests take up 2.57 % (1323.92 km^2) and 18.86 % (9722.69 km^2) of the total forested area, respectively. The remaining forested areas, 60.08 % (309,653.39 km^2), are privately or communally owned by clans, villages, and individuals. Within the area of West Kameng District and Tawang District, the balance is more extreme. No part of the forested area in the two districts is national park, and only 7 % (317 km^2) belongs to wildlife sanctuaries. There is no protected forest, and 15 % (708 km^2) of the forested area is reserved forest. The forest areas that are privately or communally owned by clans and individuals comprise as much as 78 % (3357 km^2) of the entire forested area (Dutta 2011). The protected forests are governmental plantations, and logging is possible in the reserved forests if appropriate licenses can be obtained. Such licenses are not issued for national parks or wildlife sanctuaries.

A transition in forest type occurs at approximately 2400 m altitude in the Dirang area, West Kameng District. Below this line, evergreen broadleaf trees (e.g., *Quercus lanata*, *Quercus lamellosa*, and *Schima wallichii*) and deciduous broadleaf trees (e.g., *Quercus griffithii*, *Alnus nepalensis*, and *Juglans regia* var. *hamaonia*) are dominant. Above the line, these deciduous broadleaf trees are scarce. Instead, evergreen broadleaf trees, such as *Lithocarpus pachyphylla*, *Illicium griffithiii*, and *Michelia oblonga*, as well as evergreen needleleaf trees including *Juniperus indica* prevail. In even higher zones above 2800 m altitude, evergreen needleleaf trees such as *Abies spectabilis* and *Tsuga dumosa* are more obviously dominant. The forest limit is marked by *Abies spectabilis* fir trees, referred to locally as *Wang*

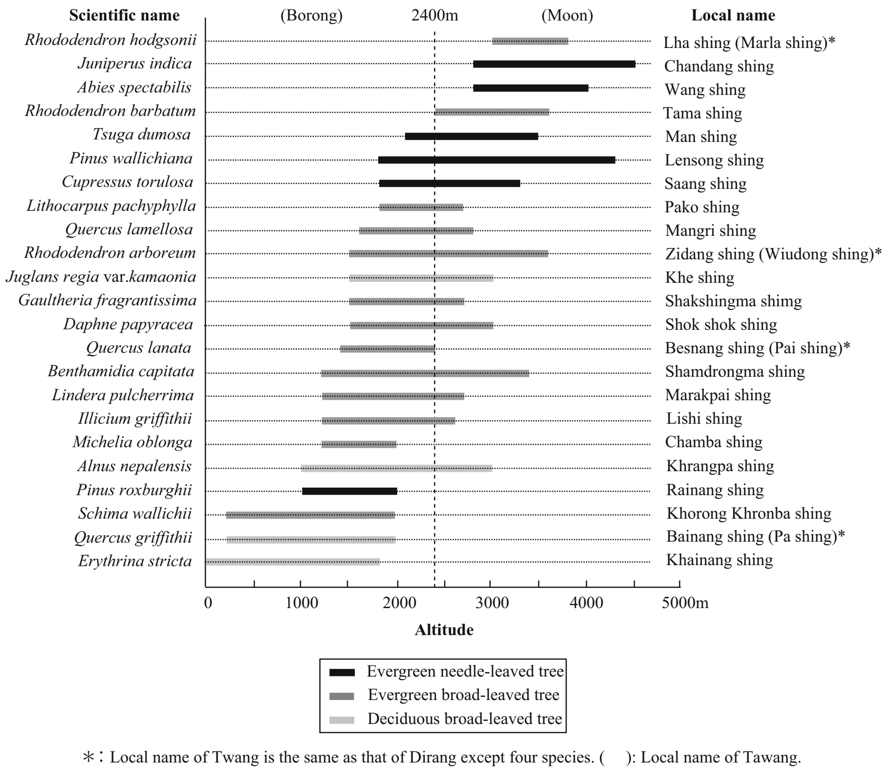

Fig. 12.2 Altitudinal distributions of tree species in the Dirang and Tawang areas.
* The local names in the Dirang area are identical to those in the Tawang area, with two exceptions. The names in the Tawang area are indicated in brackets. ** *Bainang Shing* (*Pa Shing*) is a generic name for several species of deciduous broadleaf trees belonging to *Quercus*. Produced through field observation (The local names were gathered from interviews carried out in the area, and the scientific names from Polunin and Stainton (1984) and other sources)

shing; specifically, these trees can be found in the Sela Pass at 3900 m altitude on the Tawang side (i.e., the north face), and at 4050 m on the Dirang side (i.e., the south face). Above this limit, grasslands consisting of alpine plants exist.

The local names of trees were investigated through interviews with villagers as part of this study. The most noteworthy finding was that only four tree names differed between the Dirang area and the Tawang area (Fig. 12.2). This commonality in tree names is remarkable, given the marked language differences between the two areas.

12.2 Management of Forests

The altitude-dependent distribution of forests appears to influence local people's access to, and use of, the forests. Use of Dirang's *Soeba shing*, the local name of forests to pick up fallen leaves, is a good example of such a relationship. Fallen oak leaves (*Bainag shing* [e.g., *Quercas griffithii*]) are collected from *Soeba shing* around villages and spread over agricultural fields as fertilizer for barley and buckwheat, which are produced as subsidiary crops of maize, or as a mulch to inhibit weeds or to stop soil erosion in the rainy season (Figs. 12.3 and 12.4). Note that *shing* means "tree." This area has high precipitation, and the maize is likely to fall over as a consequence of soil erosion if the ground is not covered with a mulch of fallen leaves. A layer of fallen leaves, 3–5 cm in thickness, forms on the ground when the height of the maize reaches 30 cm, normally about 2 months after seeding (Fig. 12.5). Cow owners often blend fallen leaves with cow manure. In such cases, fallen leaves, cow manure, and water are mixed together and kneaded through stomping; the mixture is left aside for 7–20 days before being spread on the ground as fertilizer.

Soeba shing are controlled to form pure forests of oak trees by weeding out needleleaf trees, specifically blue pine (*Pinus wallichiana*), locally referred to as *Lensong shing*. As a result, land cover and land use in the area exhibit unique patterns. While forests around maize fields are dominated by oak trees, those

Fig. 12.3 Forested areas, called *Soeba shing*, used to collect fallen leaves, are often next to a village's agricultural fields and are surrounded by *Borong*, forests from which fuel wood can be acquired (Yewang Village)

Fig. 12.4 Villagers spread fallen oak leaves over agricultural fields (Thembang Village)

Fig. 12.5 Fallen oak leaves are spread over agricultural fields as fertilizer for barley and buckwheat or as a mulch to inhibit weeds or prevent soil erosion in the rainy season

Fig. 12.6 A forested area called *Soeba Shing* to collect fallen leaves is behind maize fields. Forest composed of blue pine (*Pinus wallichiana*) behind *Soeba shing* is called *Borong*

around rice paddies are populated by *Pinus wallichiana*. This is because the latter do not need any fallen leaves as ground cover (Figs. 12.6 and 12.7.) (Mizuno 2014).

The fallen oak leaves are gathered between January and February every year. For 2 weeks during this period, from 7:00 a.m. until 4:00 p.m., family members, often with hired labor, gradually roll the fallen leaves downhill in the *Soeba shing* (Fig. 12.8). A rake-like special tool made of pine, a *Brack shing*, is used for this operation. Young male members of families often use simple long sticks and applied force to move lumps of fallen leaves to the foot of a hill.

Fallen leaves are gathered only within one's own land. To acquire fallen leaves from another owner's *Soeba shing*, it is necessary to pay with cash or distilled spirits. The ground of *Soeba shing* is inevitably infertile, as the litter is removed and not replaced. Thus, the surface of the soil is light rather than dark in color.

Most noteworthy in the management of *Soeba shing* is that nobody, not even the owner, is allowed to cut down any live oak tree. Only dead trees, fallen trees, and branches can be used. In the case of a village, unlawful logging is reported to the village leader, called *Tsorgen*, and the fine is a cow. Most agricultural households own a section of the *Soeba shing*.

Soeba shing are surrounded by another type of forested area called *Borong*, which is further encircled by another forest type called *Moon*. *Borong* is the local name for forests whose lumber is used for fuel wood. Such forests are conveniently located on slopes close to and facing villages. The altitude of the *Borong* is normally below ~2400 m. This type of forest consists of deciduous broadleaf

Fig. 12.7 The forest behind rice paddies next to the maize fields, dominated by blue pines (*Pinus wallichiana*)

Fig. 12.8 Fallen oak leaves are gathered between January and February every year. Family members gradually roll the fallen leaves in the *Soeba shing* downhill for 2 weeks during this period

Fig. 12.9 Deep forest locally called *Moon*. Such forests exist at high altitudes and consist mostly of evergreen needleleaf trees

trees, evergreen broadleaf trees, and evergreen needleleaf trees. Its soil is covered with some litter and has more humus than the soil of *Soeba shing*.

Moon is the local name for deep forests. These forests are on slopes not facing the villages. *Moon* can be found at altitudes exceeding 2400 m, at some distance from settlements. Timber gathering for buildings and hunting occur in such forests (Fig. 12.9). Anthropogenic impacts on *Moon* forests are smaller than those on the other two types of forests. These are largely primary forests, and their ground surface is covered with litter and the surface soil shows dark color because of humus. Their soil is argillaceous, and its moisture content is higher than that of *Soeba shing* or *Borong*.

The uses of *Borong* and *Moon* are, not surprisingly, related to their ownership. Some *Borong* forests are communally owned by clans, whereas others are privately owned by individuals. *Moon* forests, on the other hand, belong entirely to clans as common properties. In cases of privately owned *Borong* forests, their owners have the right to carry out logging operations and fuel wood gathering. Nonowners, no matter their respective clan, can also utilize such privately owned forests if appropriate permission is obtained from their owners. Similarly, people belonging to a clan have the right to acquire necessary resources from *Borong* or *Moon* forests that their clan owns. Permission is, however, necessary from the clan head when a large quantity of timber is going to be taken away. With appropriate permission, even members of other clans can acquire fuel wood. When permission is granted, distilled spirits and a white scarf are presented as a sign of respect. If trees are cut down in a *Borong* or *Moon* forest without permission, the head of its owner clan can collect a fine of 5000–15,000 Rupees from the violator. The money received as penalty is kept in a communal fund and is used for the benefit of all members of the clan. For example, such money may be used to cover the expense of rituals and a solatium for the death of a clan member.

The forests called *Moon* used to be considered "deep dark forests" that were too frightening for solitary entry. The number of people using the resources available in *Moon* forests has, however, increased in accordance with current population growth, expansion of road networks, and diffusion of automobiles. Owing to such changes, *Moon* forests are in transition from primary forests consisting mainly of shade-tolerant trees to secondary *Borong* forests of blue pines, *Pinus wallichiana*, locally called *Lensong shing*. As a result, *Moon* forests are shrinking, and *Borong* forests are expanding; hence, the former become more distant from villages every year. Although *Borong* forests are places to collect fuel wood, pines are not suitable for this purpose because they emit smoke when burned. Consequently, *Lensong shing*, the blue pines, remain untouched and are becoming abundant in many *Borong* forests.

12.3 Use of Timber and Forest Changes

There is a clear relationship between local people's use of timber and changes in the forests in today's Arunachal Pradesh. The greater the utility of a particular timber, the more quickly it is exploited. A good example is *Chamba shing* (*Michelia oblonga*) (Fig. 12.10); its wood is hard and suitable for carving, and it has gained popularity as a material for furniture making and building. The market price of one cubic foot of *Chamba shing* (dimensions: 12 ft × 12 in × 1 in. 365.8 cm × 30.5 cm × 2.5 cm) (Fig. 12.11) was already as much as ~200 Rupees in 2009, and it rose to ~500 Rupees in 2010. The soaring price led to its extensive exploitation. Although *Chamba shing* was common in *Moon* forests in the past, it is now difficult to locate this tree.

A number of trees other than *Chamba shing* are employed as construction materials. The following tree species are locally known to be suitable for such purposes: *Man shing* (*Tsuga dumosa*); *Khe shing* (*Juglans regia* var. *kamaonia*); *Wang shing* (*Abies spectabilis*); *Khorong khoronba shing* (*Schima wallichii*); *Kharangpa shing* (*Alnus nepalensis*); and *Besnang shing* (*Quercus lanata*). *Lensong shing* (*Pinus wallichiana*) from secondary forests, an oily and hence water-shedding tree species, is regularly used for the outer walls of buildings. Logging of these trees is increasing, just as the exploitation of *Chamba shing* is gaining ground. Currently, there is a significant demand for hard timber, namely *Chamba shing*, which has been used for the production of furniture, as has *Khe shing*.

The price of all timber used for construction is soaring. Many trees of *Chamba shing* have been cut down for commercial purposes and sold to Delhi and Mumbai,

Fig. 12.10 *Chamba shing* (*Michelia oblonga*)

Fig. 12.11 Very hard timber obtained from *Chamba shing* (*Michelia oblonga*) is used as material for furniture. Its price is soaring, and illegal logging of this tree is common

as well as to the states of Haryana, Punjab, and Gujarat. They are now scarce, and their prices are very high.

The Indian central government and the state government changed the commercial logging regulations for *Chamba shing*, *Lensong shing*, *Wang shing*, and *Man shing*. Licenses became necessary for commercial exploitation of these timbers. Such licenses, however, were not required to log these trees for private purposes. This became a loophole, and massive logging was carried out, along with bribing of governmental officials. About 30 % of forests in the state are said to have disappeared within 9 years after the change in logging regulations in 1987. The Supreme Court of India then ordered a ban on issuing licenses and prohibited commercial logging entirely. The decision stopped large-scale logging. However, illegal logging for commercial purposes on a small to medium scale continues today.

While the government does not permit commercial or private logging, the actual owners of forests, i.e., mostly clans, allow logging for private purposes. This is currently functioning as a loophole for certain levels of commercial logging. Although clans prohibit logging of *Chamba shing*, other commercially valuable trees are cut down with approval from clans. Logged timbers are covered and placed on trucks to be transported from the forests.

Gathering of fuel wood is an important, day-to-day use of forests for villagers. As explained earlier, this task is performed mostly in *Borong* forests. Trees employed for this purpose are *Besnang shing* (*Quercus lanata*), *Bainang shing* (*Quercus griffithi* and others), and *Mangri shing* (*Quercus lamellosa*). Charcoal made from *Besnang shing* and *Bainang shing* lasts longer than that made from other timber and is considered to have high utility. *Mangri shing* used as fuel wood can produce strong heat, which is considered its advantage. An increase in the consumption of fuel wood is encouraging local people to look for wood, not only in *Borong* but also in *Moon* forests. Large numbers of *Pako shing* (*Lithocarpus pachyphylla*) have been and are being cut down and removed from *Moon* forests. Above 3000-m altitude, trees of *Tama shing* (*Rhododendron barbatum* and *Rhododendron campanulatum*) are indispensable fuel wood for pastoral people. The characteristically large leaves of a similar tree, *Lha shing* (*Rhododendron hodgsonii*) (Fig. 12.12), are used by these people to wrap butter and cheese (Fig. 12.13).

Several other useful resources are found in the forests of the state. Berries of *Lishi shing* (*Illicium griffithii*) are collected between November and December, and when powdered are used as a spice (Fig. 12.14). The price of these berries is as high as 25 Rupees per kilogram when sold by villagers to local merchants. *Borong* forests at lower altitudes produce berries of *Lishi shing* that are larger and hence more favorable; the abundance of this tree in *Moon* forests has proved to be extremely useful. *Shokshok shing* (*Daphne papyracea*) is an evergreen broadleaf tree and another useful resource. It is the raw material used for traditional paper (Fig. 12.15), called *Boi shuku*. Strips of paper used for religious purposes, called *choephan* in the Dirang area and *shukphan* in the Tawang area, are mostly made from this tree (Fig. 12.16). *Khainag shing* (*Erythrina stricta*) is a deciduous

Fig. 12.12 *Rhododendron hodgsonii*, locally called *Lha shing* (*Marla shing*)

Fig. 12.13 Leaves of the *Rhododendron hodgsonii* are employed by pastoral people as wrappers for butter and cheese

broadleaf tree, often used for making fences to encircle houses due to its thorny structure (Fig. 12.17). This tree is said to be easy to plant, as a cutting simply grows when placed in the ground. *Rainang shing* (*Pinus roxburghii*) is a pine tree, and its

Fig. 12.14 Berries of *Lishi shing* (*Illicium griffithii*), which can be ground for use as a type of spice, are traded at high prices

Fig. 12.15 Local paper is created by using the fiber of trees of *Daphne papyracea*, locally called *Shokshoku shing*

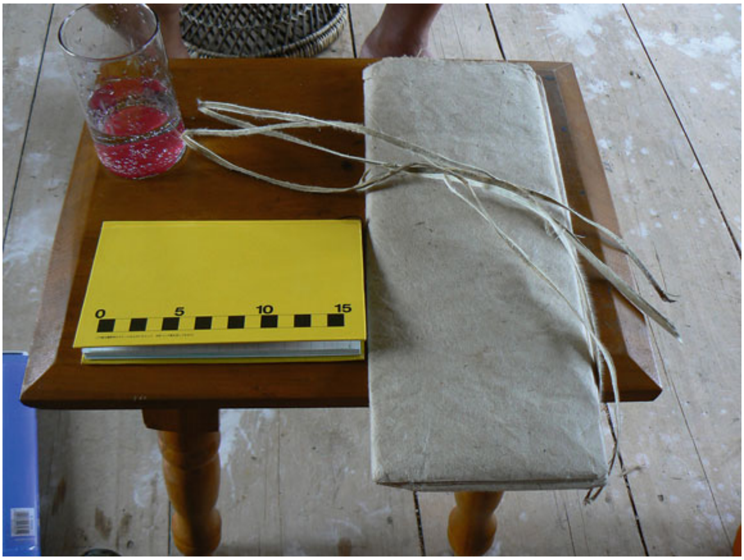

Fig. 12.16 Paper called *Boi shuku* is produced from trees of *Daphne papyracea*

Fig. 12.17 *Khainag shing* (*Erythrina stricta*) is a deciduous broadleaf tree, often used for making fences to encircle houses due to its thorny structure

Fig. 12.18 *Rainang shing* (*Pinus roxburghii*) is a pine tree, and its oil can easily be obtained by placing a container at the base after making an incision on the trunk

Fig. 12.19 Stone-built fire pit, locally called *saang bum* in the Dirang area and *budpa* or *sangkhuk* in the Tawang area. Leaves and branches of *Saang shing* (*Cupressus torulosa*) and *Chandang shing* (*Juniperus indica*) are burned to produce incense smoke used in Tibetan Buddhist ceremonies

Fig. 12.20 Flowers of *Zidang shing* (*Rhododendron arboreum*) are used as ingredients to produce a juice drink

Fig. 12.21 *Rubia manjith*, locally called *laningru* or *leinauri*. The red robes of monks are dyed using colorant extracted from the roots of these plants

Fig. 12.22 Berries of Chinese spice (*Zanthoxylum piperitum*), locally called *Khagei*, were used as a form of tax called *khray* until 1946

Fig. 12.23 A rod-shaped piece of fuel is produced by inserting burned and carbonized yak dung into the device (This photograph was provided by Mr. Dutta of the World Wildlife Fund (WWF))

oil can easily be obtained by placing a container at the base after making an incision on the trunk (Fig. 12.18). The oil from this tree is sold commercially to industrial firms. Leaves and branches of *Saang shing* (*Cupressus torulosa*) and *Chandang shing* (*Juniperus indica*) are burned in stone-built fire pits, called *Saang bum* in the Dirang area and *Budpa* or *Sangkhuk* in the Tawang area, to emit incense smoke for Tibetan Buddhist ceremonies (Fig. 12.19). Flowers of *Zidang shing* (*Rhododendron arboreum*) are used as ingredients to produce a drink (Fig. 12.20).

In this area, specialty goods were collected as tax by the Tawang Monastery and Tibetan government until 1946, including *Rubia manjith* (locally called *Laningru* or *Leinauri* (Fig. 12.21)), *Daphne papyracea* (locally called *Shokshoku shing*), and *Zanthoxylum piperitum* (a kind of Chinese spice locally called *Khagei*) (Fig. 12.22). Monks' clothing is dyed with a red stain produced from *Laningru*.

The use of yak dung as fuel has also been promoted. Dried yak dung was formerly used as fuel in the Monpa area, but it had been replaced with fuel woods from forests because it was very smoky when burned and more labor intensive to collect. The use of yak dung became rare except in high-altitude areas above the forest line. To revitalize its use as a source of energy, a device to streamline its production process was invented. This device takes burned, carbonized yak dung and converts it into a rod-shaped piece of fuel (Fig. 12.23).

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Chapter 13
Institutional Dimensions and Changing Role of Forest Management Governance in Dehradun Valley

Poonam Kumria, R.B. Singh, and Koichi Kimoto

Abstract Forests are under intense pressure and the country faces significant timber and fuelwood deficits. There was an intense debate throughout the 1980s as to who could most effectively manage forest resources. Forest are important for rural livelihood. There arises conflict between government institutions and local people who are dependent on these forest resources. The Forest Policy envisages a process of joint management of forests by the state governments and the local people, which would share both the responsibility for managing the resource and the benefits that accrue from this management. But at implementation level village communities have not been involved in forest management because in the valley forests are under Reserved Forest category. Over the past several years the focus in forestry has shifted towards the planning and conservation. Current forest management systems need significant strengthening to monitor forest and community. The study analyses the factors leading to success and failure of the JFM targeting perceptions and operational difficulties faced by forest managers.

Keywords Forest depletion • Social forestry • Forest policy • NTFPs • Forest Protection Committees • Joint Forest Management Committee

13.1 Context of Research

India's compliance with United Nations policy on forests and indigenous people is seriously limited by the centralization of forest management and lack of recognition of indigenous people and their rights, and the situation with regard to traditional

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forest related knowledge can only be understood within this wider context. Widespread resistance to state forest policy and law throughout India's history of centralised forest management has been fuelled by the fact that about 90 % of India's 64 million hectares of forests are under state ownership, the rest being in community and private forests. Moreover, it is predominantly the country's indigenous/tribal peoples' areas that have been declared as state owned 'forests'. Also, state control over the forest land is weak and there is considerable encroachment by individuals and communities other than the indigenous people in state-owned areas (Baland et al. 2007). The tribes were there long before the state started encroaching on their lands and the condition of both the tribal and the forests then were far better than it is today. This rift still can be seen in the valley between officials of Rajaji National Park and Gujjar tribe. However, the laws enacted so far in India have largely ignored the forest dwellers and more particularly the tribal people.

The crisis lies not in the magnitude of the problem but in the inability of the state and social institutions to find solutions. The contradictions within a society undermine social and organizational mechanism, making it impossible to find alternatives for conflicts and crisis. Solutions must be based not only on capital investments, production and technology but also on understanding and agreements. The inequalities-individual or spatial, urban-bias central authority, and production system with low rate of labour absorption, is responsible for increasing dependence of population on natural resources (Arizpe et al. 1994). Forest has the history of the inter-twined, ever-interacting system of the state, forest and people living close and in the forest. The forest dwellers represent the societies insist on subsisting on their local resources and the state represents the forces of modernization, which control the resources. The change in forest resources affects both the state and the people. The crisis is not only of the depletion of forest but of the relationship among state, people and the forest (Pathak 1994). The concept of people's participation in management of forests is not new to India.

The country historically has great traditions of protecting and managing forest as common resources. Every village hamlet and community ensured that the utilisation of natural resources including forests did not exceed the ecological carrying capacity (Guha 1989). The economic and political colonization of the country adversely affected the traditions of conservation of sustainable utilization of resources (Gibson et al. 2000). The forests and the people, which grew under the mutually beneficial relationships, suffered together, as the growing population put ever-increasing demands on the resources (Agarwal and Chhatre 2006). The Millennium Development Goals call for the integration of the principles of sustainable development into the forest policy. Environmental sustainability is being mainstreamed in forest policies around the world, particularly since UNCED, while the integration of the goals of poverty and hunger reduction in forest policies and plans is less widespread (www.legalserviceindia.com/article/1215)

13.2 Methodological Considerations

Dehradun district lies in the state of Uttarakhand, which is carved out from Uttar Pradesh in November 2000. The state was carved out from Uttar Pradesh taking out 13 districts covering an area of 53,483 km^2. The state of Uttarakhand recorded 13 districts, 49 tehsils, 86 towns and 16,826 villages. The population of the State as per 2011 census is 10,116,752. The decadal growth was 19.17 % while previous decade it was 19.20 %. According to 2011 census, the Dehradun is the second largest district in terms of population (1,698,560) after Haridwar district (1,927,029). It is one of the highly populated districts of the state. It has highest literacy rate in the state. The valley is bounded by the lesser Himalaya in the North and Siwaliks in the South, while rivers the Ganga and the Yamuna form eastern and western limits. Within the valley the elevation ranges between 315 and 1000 m. Dehradun is a longitudinal valley lying between 29° 55′ and 30° 30′ N latitude and 77° 35′ and 78° 24′ E longitudes. Its length is 100 km and width varies from 20 to 25 km covering an area of 2250 km^2 (Fig. 13.1).

The wide altitudinal variation ranges from low lying valley to the Himalayan ranges, leading to variation in lithology and topography; it results in variations in climatic and edaphic conditions. It has produced great variety of vegetation. In the valley about 48.62 % of the land is under forest and about 24.08 % of the forest land is of open category. The changes in vegetation cover not only affected by human presence but also by the physical factors operating in an area.

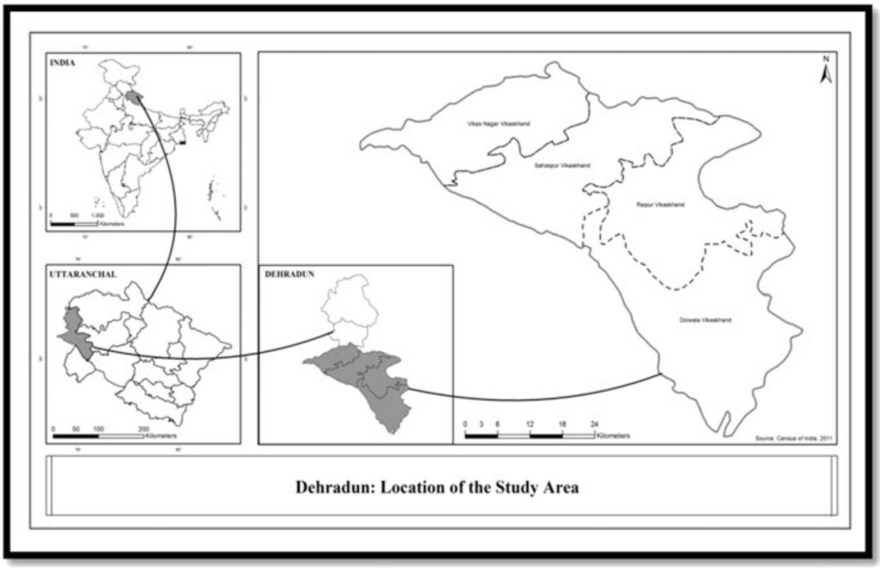

Fig. 13.1 Location of the study area

The research methodology of this study includes data generated from the field through structured as well as unstructured questionnaire. In total 80 forest officials and scientists have been consulted on these issues in order to develop comprehensive framework for sustainable forest management. The unstructured questionnaire and field book has been maintained for policy makers regarding – financing the poor people, perception of people about social forestry, forest action plans, local community participation in these programmes, etc. Simple statistical techniques and diagrammatic representation is also done.

The non-parametric Chi Square test have been performed to analyse the distribution of responses given by the forest officials. The test has been calculated with the use of SPSS 12. It was assumed that responses of forestry staff would be uniformly distributed across different response categories because all of them follow the same procedures, rules and regulations of forest management and JFM. Chi-squared goodness-of-fit tests were used to examine whether responses of forestry staff differed across the various response categories, at the 5 % significance level. The response categories chosen for factors of success and failure of Forest management were: AG: Agree, ASE: Agree to some extent; N: Neutral and DA: Disagree. The assigning importance weights to response categories has also been done in descending order of importance (AG: 4, ASE: 3, N: 2, and DA: 1). For each question, the number of respondents assigning each particular importance level were multiplied by the corresponding weights and these were summed to obtain the total score.

13.3 Unlocking Forest Policy

In ancient India it was generally accepted that forests and the communities living in the forest were not controlled by the rulers, because the forest was not seen as a source of revenue or commercialisation. The effects of industrialization side by side with British rule in India in the eighteenth century brought about dramatic changes: the need to meet the growing demand for timber (associated with the expansion of trade and commerce as well as the railway boom of the late 1800s) and a growing dissatisfaction with the legal restrictions imposed by previous legislation, led to the institution of the Indian Forest Act in 1878, according to which the nation state was recognized as sole proprietor of classified forest lands. The first Forest policy 1894, failed to lay down the guidelines of the proper utilisation of the Indian forests (Jha 1994). A new Indian Forest Act in 1927 incorporated few substantive changes over the 1878 Act, and remains the legislative basis for state forest management today (Table 13.1).

Joint Forest Management is a forest management strategy under which the Forest Department and the village community enter into an agreement to jointly protect and manage forest land adjoining villages and to share responsibilities and benefits (MoEF 1990). The village community is represented through an institution specifically formed for the purpose. This institution is known by different names in

Table 13.1 Indian national forest law and policy, 1878–1988

Year	Law	Relevant measures
1878	Indian Forest Act	State is sole proprietor of classified forest lands
1890	Forest Department Resolution	Previous rights of access and use redefined as 'privileges' for specific tribes, castes, villages and organizations
1927	Indian Forest Act	Few substantive changes over the 1878 Act. It remains the legislative basis for state forest management today. The Indian Government adopted the 1927 Act after it gained independence in 1947
1952	National Forest Policy	Set out guidelines which were, for the most part, directed towards the supply of cheap timber and non-timber forest products for state-sponsored industrialization and modernization
1976	Indian Forest Act added to the concurrent list of the Constitution of India	Central government and states given shared control over forest matters
1980	Forest Conservation Act	The central government reasserted some of its control over forest-based resources. The 1980 Act restricts the state government's power to de-reserve a forest, and it restricts the use of forest land for non forestry purposes without the prior approval of the central government
1988	The National Forest Policy	Envisaged people's involvement in the development and protection of forests for the first time, never translated into law

Source: Compiled from MoEF 1988, 1990, 1998

different states (e.g. Vana Samaraksha Samitis in Andhra Pradesh and Hill Resource Management Societies in Haryana) but most commonly referred to as Forest Protection Committee or FPC. In some states, panchayats can also enter into JFM agreement with the Forest Department. Under JFM, the village community gets a greater access to a number of Non Timber Forest Products (NTFPs) and a share in timber revenue in return for increased responsibility for its protection from fire, grazing and illicit harvesting. The details vary from state to state as each state has issued its own JFM resolutions/rules. The essential difference between "social forestry" and JFM is that while the former sought to keep people out of forests, the latter seeks to involve them in the management of forest lands. JFM also emphasises joint management by the Forest Department and the local community. JFM is an outcome of the realisation that active and willing participation of the forest fringe communities is necessary for any forest regeneration programme to succeed. Further, village communities would have little incentive to participate unless they benefit directly and have sufficient authority to be effective (MoEF 2000a).

To promote afforestation, tree planting, ecological restoration and eco-development activities in the country, the National Afforestation and Eco-Development Board (NAEB) was set up in August 1992. The main function of the NAEB is regeneration of degraded forest areas and lands adjoining forest areas, national parks, sanctuaries and other protected areas as well as the ecologically fragile areas (india.gov.in/sectors/environment). Four Eco Task Force (ETP) Battalions are being supported under the Eco Development Forces (EDF) Scheme. These battalions are located at Pithoragarh, Samba, Bikaner, and Dehradun (MoEF 2000b). Two new battalions have been approved in Assam. All ETF Battalions have undertaken works like raising nursery, plantation and protection measures to protect the plantation area. They have also constructed stone dam as also other soil and moisture conservation works. Besides, the battalions also take up maintenance of old plantations. NAEB also has facilitated implementation of the Centrally Sponsored Scheme, 'National Afforestation Programme' (NAP) through 28,281 village level institutions to realize the dream of Joint Forest Management across the country. These institutions, commonly named Joint Forest Management Committees (JFMCs), are organized into district level federations named as Forest Development Agencies (FDA) which play the pivotal link between the Central Government and the JFMCs for natural resource management. This institutional framework encompasses all States and Union Territories of the country.

The scheme has supported 782 FDA projects in all including 31 projects for special problem areas like 'Jhum'/shifting cultivation. It continues to be the flagship scheme of NAEB, in so much as it provides support, both in physical and capacity building terms, to the Forest Development Agencies (FDAs) which in turn are the main organ to implement Joint Forest Management (www.india.gov.in/sectors/environment/national_board.php). This decentralized two-tier institutional structure (FDA and JFMC) allows greater participation of the community, both in planning and implementation, to improve forests and livelihood of the people living in and around forest areas. The village is reckoned as a unit of planning and implementation and all activities under the programme conceptualized at the village level. The two tier approach, apart from building capacities at the grassroot levels significantly empowers the local people to participate in the decision making process. Under Entry Point Activities, community assets are created with a 'care and share' concept (MoEF 2003).

The Government of India (2009) of the National Afforestation Programme (NAP) are being issued to further decentralise the project cycle management of the Scheme with a view to expedite fund transfer to the village-level implementing organisation, that is the Joint Forest Management Committees (JFMCs) and Eco-development Committees (EDCs), to embed the Scheme in the overall forestry development programme of the State/ UT, build capacity of the institutional actors and institutions, and promote livelihoods of JFMC members by linking forest development to value addition and marketing of forest products. The Scheme will be implemented by a three-tier institutional set-up, namely State Forest Development Agency (SFDA) at the State/UT level, Forest Development Agencies (FDAs) at the forest division level, and Joint Forest Management Committees (JFMCs) or Eco-development Committees (EDCs) at the village level (www.india.gov.in/sectors/environment/national_board.php). The focus of the institutional work is towards regeneration and management of forest resources while strengthening the village level capacity for the same.

The state neglected local people very much in the valley, while changing its priority from commercial extraction to forest protection till now. Although there is a shift in the government policy, the commercial extraction, wood smuggling and collection of Non wood forest products is still going on in the valley causing severe damage to forest stock especially in the settlement areas. The survey conducted among officials of forest departments, and scientists from the forest research organization indicated that many economic, legal, and energy and infrastructural provisions are provided in the policy but their implementation is not hundred per cent. The Forest Department raises plantation of quick growing species on common land and revenue wasteland with the help of panchayat (Jena et al. 1997). It manages the plantation for 3–5 years and then transfers the charge to village panchayat. The village gets grass, branches and twigs free for collaborating with the project. The power structure and the social heterogeneity make impossible for the villagers too have the benefits of social forestry as they are ignorant of the rules and their rights. There is no relation of development planning and presence of the resources in the valley. The encroachment of the forest land is a common feature, which reflects the faulty government policies. The survey indicates that 55 % forest officials responded that there is economic assistance, while only 2 % assistance is there for energy sector. The provision of economic assistance- direct or indirect is given in the policy (over 72% of the responses) but analysis indicates that implementation is only 27 % agreed by the respondents. Similar is the case of legal rights given in the policy. There is less help either in planning process or implementation on energy and infrastructural issues.

Choice of management system is also an important issue. Management can range from deliberate non-intervention to various intensive forms of use (Ostrom 1990). It also varies from management directed primarily at a single end product such as recreation, hunting, or timber to management that tries to satisfy many different user groups – multipurpose forest management. For nearly four decades after independence the process of commercial exploitation and degradation of the forest continued. The importance of forests for the ecological and economic stability of the country was realized by the conservationists, foresters, as well as the government, which necessitated the reexamination of the policy, laying emphasis on the conservation and sustainable utilization of our forest resources (Baland et al. 2006).

13.4 Forest Management

Forest is the overall administrative, economic, legal, social, technical and scientific aspects involved with the handling of conservation and use of forest. It implies various degrees of deliberate human interventions, ranging from action aimed at safeguarding and maintaining the forest ecosystem and its functions, favoring socially or economically valuable species or groups of species for the improved production of goods and environmental services (FAO 1991). It is based on the knowledge of a number of basic subjects, such as silviculture, ecology, geology, geography, pedology, botany, pathology, economics, and finance, etc. (Prakesh and

Khanna 1979). In the past the country had good dense forest. The population growth was not alarming. The demand for the forest products was also within the carrying capacity to which existing forest could sustainably produce. Deforestation was never perceived as a problem. Consequently, management of forest in the pre-independence period focused on following three main tasks:

- Control of composition and structure of the growing stock,
- Harvesting and marketing of forest produce,
- Administration of forest property and personal.

The forest management practices prevailing in the pre-independence India continued till eighties. During this period the relationship between forest and people changed drastically. On one hand, the anthropogenic pressure on the existing forests increased manifold and community control over the common resources weakened. On the other hand, unsustainable harvest and use of forest resources increased by leaps and bounds. Consequently, deforestation rate increased at the alarming rate. So, the focus of forest management changes on the following issues:

- Restoration of degraded forest,
- Development of medium and dense forest,
- Conservation of existing dense forests and its resources.

Restoration of degraded forest requires protection and reforestation. The development and conservation of existing forest requires a mechanism sustainable forest harvesting and accounting of forest stock available in the area. In view of this multiple management of forest becomes very important. It includes protective, climatic, productive, scientific and recreational management. While managing a forest landscape, all such purposes are not equally synchronized. One purpose has to take precedence over the other. However, based on the priority, we can adjust our management objectives. Although till date, in the case of management of dense forest, timber production has received the utmost priority (Bebarta 2002). With the increasing problem of deforestation and rift between the state and people, the management of forest area has become more important. Similarly, the degraded forests are required to be tackled for rehabilitation work on war footing.

Sustained yield has been an age old principle of forest management. The principle of sustained yield envisages that a forest should be so exploited that the annual or periodic felling does not exceed the annual or periodic growth (Prakash and Khanna 1979). The transition from the sustained yield management for wood to sustainable forest management is the main challenge.

The region has an impressive array of community forest management systems, both informal as well as officially constituted. Unofficial community management, with diverse institutional arrangements on all legal categories of forest lands, has co-existed with formally constituted Van Panchayats, and in fact predates them. Democratic and autonomous community management of legally demarcated village forests (on Forest and Revenue Department land) by elected forest councils, Van Panchayats (VPs), has existed in Uttarakhand for over seven decades. The institution of Van Panchayats was created in response to protests against forest reservation through notification of the Kumaon Panchayat Forest Rules in 1931. Although it has undergone several changes since, it remains a unique example of community based forest management in India possible under section 28 of the Indian Forest Act, 1927 (Singh 1999). These forests are demarcated as village forests under the Act and are entered in the land records in the panchayat's name. All of the van panchayats in the hills, are thus formally empowered to initiate rule making procedures and implements the rules they craft so as to use and protect theri forest resources in accordance with their needs (Agrawal and Yadama 1997).

Various studies have shown that although the effectiveness of Van Panchayats varied from village to village, the condition of panchayat forests has been generally as good as or better than that of Reserve Forests, particularly those near habitations. The early Van Panchayats enjoyed considerable autonomy in decision-making and control over the forest (Bonati 1991). They balanced the maintenance of ecological services such as soil fertility and water source protection with grazing, collecting and other forest uses necessary to support local livelihoods (Somanathan et al. 2005). High stakes in the forest and strong bonds of trust among villagers allowed many of the Van Panchayats to remain successful for many years. Many have displayed remarkable resilience and adaptation to changing internal and external environments. However, the total number of Van Panchayats remained low for many decades, partly due to the weak capacity in many villages to negotiate the bureaucratic procedures for getting a Van Panchayat constituted. Also people saw little advantage in getting village forests notified as they continued to assert customary authority over their commons on the strength of the traditional sal boundaries. Such community forest management continues to be widespread and is growing outside any formal legal framework on all categories of legal forest lands. This is particularly so in villages away from major roads where the commons are still central for sustaining the local subsistence economy. Traditional Lath Panchayats, informal Van Samitis and more recently, increasing numbers of Mahila Mangal Dals are regenerating and regulating the use of reserve and civil/soyam forest lands, often compelling unofficial cooperation by staff of Forest and Revenue Department.

13.5 Forestry Education and Training Programmes

Education and training are vital parts of the forest management. It helps to make aware the community about their rights and different provisions given by the government. It fills gap between the society and forest officials. Although there are lots of training programmes as well as informal meetings and involvement of NGO in the valley, some surveyed scientists feel that these programmes are not successful as there is inherent conflict between people and the state. On the whole majority (over 63 %) of the scientists feels that these programmes are successful in bridging the gap between the people and government to some extent.

The importance of training and education is a constant factor in all the work of forest quality. These programmes work in two way directions, as experts also learn from the grassroot experiences. These training programmes are organised by the forest department for both local people as well as for the staff at various levels. Professional training programmes for Forest Rangers, Foresters and other field staff. Workshops are also organized to make local people aware about different scientific techniques of plantation and maintenance. Tailor-made special training packages are designed for van panchayats, village panchayat and local community. Decentralised training programmes for van panchayats are also conducted in different Forest Divisions. Training on different aspects of wildlife management is conducted at Corbett (Wildlife) Training Centre, Kalagarh. Demand-driven short-term programmes and capsule courses are also arranged. Professional training programmes for Forest Rangers, Foresters and other field staff are being conducted at Forestry Training Academy, Haldwani (Rawat 1999).

The forest practices that are community-based and community-managed often fare better and are more sustainable than those models that are formulated and controlled by the state. This inclusive approach is seen as helping to alleviate the issues of alienation of locals and the disintegration of traditional cultures and livelihoods. Government and business practices do not always respect this, which can lead to unwanted interference. One such obstacle to self-determination in this region is the governmental policy of turning increasing amounts of forest land throughout various parts of India into parks and sanctuaries. The result of this has been the forced resettlement of indigenous peoples from their forest dwelling communities to areas that are outside their traditional habitat. The two way involvement is necessary to stop forest degradation. There are various steps taken by the forest department to assess the stock, loss, degradation, and people perception about the degrading forest resources in the valley.

13.6 Forest Assessment Systems

Access to forest inventory, land use practices, soil erosion area, land degradation, salinity, lowering of water table, farming practices, scientific research are important component of sustainable forest management. Access to this database is very important for planning and implementation of the plan. Sufficient quantum of hardware and software has already been acquired by the Forest Department. Regular trainings are organized for staff and officers. Office staff is trained with primary focus on Word Processing and use of Spreadsheets, etc. Department uses database software in many of its functions like Fire Information Database, Inventory Management System, Establishment database, etc. Department has created a GIS using some data layers like river systems; cities, towns, villages; forest rest houses; roads; territorial entities like ranges, etc. Assessment systems, guidelines, code of practice and technical manuals all help people charged with managing a forest landscape have information about best practice (Dudley et al. 2007). The

Table 13.2 Different assessment systems

Assessment system	Accessibility (ranking)[a]		
	Scientists	Community	Women
Inventory	VH	VH	VH
Scientific skills	VH	L	VL
Scientific research	VH	VL	VL
Latest technology	VH	VL	VL

Source: Fieldwork
[a] *VH* very high, *L* low, *VL* very low

survey with the forest officials indicated that there exists very high accessibility among scientists to various assessment systems for forest management in the valley (Table 13.2).

The community and the local women also have very high accessibility when it comes to the identification of species and knowledge of forest inventory. Forest officials indicated that people in the valley are well versed with the species in their areas. They also know which tree or species should be used for what and when. The local women have more information than men as they have to go forest more frequently than men either for collection of fuelwood, fodder or NWFPs. Their assessment is affected by daily requirement of each household. People's image about environment and resource is also transmitted through their social, cultural background that affect their behaviour and in terms perception. Perceptions are created and recreated by trying to fit them into previous frameworks. These perceptions are transmitted through oral traditions, schooling or the mass – media (Badola 1998). Since, everyone equally has to face consequences of deforestation and degradation, so the responsibility lies with everyone; though, in different proportions. With the use of remote sensing and GIS techniques Forest Survey of India, assess the whole forest area of the country. There are various institutes in the valley which are working on the forest resource assessment in the reserved as well as outside tree areas.

13.7 Evaluating Management Plans

Forest in India are owned and managed by the government. Therefore, the ownership is public in nature. Public ownership of forest enjoins upon the state a responsibility to manage forests is such that it maximizes generation of public goods. With changing policy of forest exploitation to protection of the forest, the perspective of government changes with time. Although commercial exploitation still exists many a times ignoring the people who are very much dependent on the forest resources especially in the valley. A management plan is largely about resolving conflicts, choosing goals, objectives and making decisions. This management plan in forest parlance is called "Working Plan". A working plan is a written scheme of management aiming at continuity of policy, controlling the treatment of a forest (Government of India 1983). It is the simplest possible statement of what is known about the working plan areas; its configuration, soil, climate, vegetation, its possibilities; what has been done in the past, what should be done in the future, how it should be done and what records should be kept.

The main objectives of Dehradun management plan are still concentrating on commercial exploitation of the timber and other NWFPs as indicated by the Forest Survey of India officials. Objectives of management plan changes with the passage of time in Dehradun Valley. Since the inception of forest management the primary objectives of drawing a management plan was to maximize timber production from the forest. Therefore, working plan aimed at evolving a felling programme so that the entire accessible part of the forest would be taken up for harvesting wood in a definite period. However over the years, in order to obtain sustained yield of timber on a long-term basis, regeneration strategy was incorporated in the working plans.

During this period the methodology of computing the timber projection was basically very rude and was based on thumb rule and cursory observation (Bebarta 2002). Later, the practice of partial enumeration of trees and other improved methods to calculate timber yield were used. This method of enumeration was continued till 1960s. With the advancement in science and technology and application of remote sensing and GIS techniques have changed the whole scenario of enumeration. Now, all over the country, detail inventory of forest resource is done. Over the years, the role of forest changed radically. Timber producing function gradually gave way to societal and protective functions of the forest areas. With the passage of time, even the social values of forest are also changing, leading to host of intractable problems and constraints.

The management plan for Dehradun valley is prepared by the Forest Department, Nanital. The plans are based on the local conditions and problems. The time plan for these is 10 years. After every 10 year, the plans are written again though with few changes in the plans, policies and implementation programmes. The basic structure of the management plans has not changed much since the first plan was prepared in 1888 for the Dehradun valley. It also contains planning and conservation policies and the major objectives that have to be followed during a course of time. There are different issues which are taken care of while formulating the plan. The first volume of the plan comprises of number of chapters discussing geology, geography, soil, vegetation type, and diameter of the trees, exotics, pest control and various other issues (Working Plan Circles 2000). The second volume contains appendices of forest ranges. It contains detail information about area under sal, under chir, under miscellaneous, plantation, etc.

The survey indicates that over 65 % of the forest officials and scientists ranked collection of forest information and soil inventory as first priority in the current working plan. The involvement of local people in the management plan has been indicated as second priority only by 6 % of the officials. In view of people's dependence on forest and non participatory approach, the management plans most of the time fail on implementation part. Forest ecosystem services, such as replenishment of land, sequestering of carbon, protection from weather events, and recreational uses, remain threatened. The high population growth and poverty accelerate forest degradation and it is a major factor leading to tussle between the people and forest officials. Apart from this, plans are executed for 10 years, any social change or cultural change cannot be accounted in the present time. Consequently, leading to gap in the planning and forest management which, increased rift between forest officials and village people. Proper forest management was started in 1871 when mapping and demarcation of the forest area was started. The valley has gone through 11 forest working plans starting from Fernandez's Plan in 1888. During the British period, the sole purpose of forest management became to redistribute economic gains in favour of the empire (Jha 1994). This was achieved by commercialization of timber, restriction of the rights of local people, and large-scale deforestation (Gadgil and Guha 1995).

The exclusion of local people from forest resources led to conflicts between the empire and local people. Due to heavy pressure of fuelwood demand, illicit grazing, and wood smuggling, the forest degradation increased in the valley. The main objective of forest working plans is to develop the stock in under best possible conditions of growth. The survey indicated that enumeration process is most successfully carried out under these plans. Over 33 % of the surveyed officials think that the success rates of the past management plans are only below 30 %. In the earlier plans the forest continued to improve under improvement felling, climber cutting, coppice of unsound stock etc. The local people searched for a solution through various non-violent movements, although some eventually turned to violent means. Although, some forest were under severe destruction due to uniform group selection system. The improved felling, exploitation of minor products and fire protection is rated as 60–90 % successful in various plans.

The usual tendency to mark the trees even where there is nothing to mark resulted into heavy felling earlier in the valley (Working Plan Circles 2000). There are many experiments like – shrub cutting, burning, ploughing planting of sal transplants has been done with not so success to regenerate degraded sal forest in the valley. All other works are relatively low on the success rate. While the social issues and involvement of local people in the working plans, got very less considerations. Prior to the British occupation the local rulers derived an income from the forest in the form of royalty. There was no control on felling and any one could fell any tree anywhere and export by paying royalty. The system was devoid of conservancy and consisted of colossal destruction and waste of forest resources (Fig. 13.2).

Forest management regimes did not take the cognisance of existing examples of community-based natural resource management such as village ponds, sacred forests, forest panchayat (Van Panchayat), and informal tree tenure for collection of NTFP, and continued regulatory and authoritarian forest management practices (Jodha 1990). This alienated the communities from being a responsible part of the ecosystem, and resulted into unsustainable and destructive harvesting of products and loss of bio-diversity (Arnold and Stewart 1991). Peoples' participation was first experimented with the launch of social forestry programme in mid-1970s. However, at that time "I work and you participate" mindset of foresters did not result into meaningful participation of communities in forest management (Tewari and

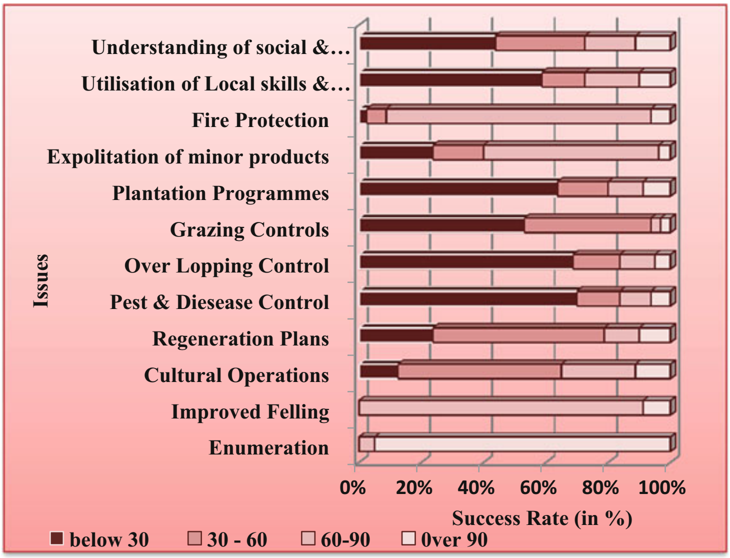

Fig. 13.2 Past management plans

Campbell 1995). In recent years there has been a shift towards participatory approaches in forest management and biodiversity conservation. The Government of India (1988) declared that local communities were to be involved in natural resources conservation. Subsequently, in 1990 the Indian Ministry of Environment and Forests issued a circular for Joint Forest Management (JFM) and resource sharing. The JFM approach seeks to develop partnerships between state forest departments (as owners) and local community organizations (as comanagers) for sustainable forest management (Agarwal 2006). The main stakeholders of JFM are Forest Department and the local people. Other interest groups include NGOs, panchayats (village councils), politicians, local administration, academicians, and environmentalists. It is becoming clear that different stakeholders view JFM quite differently and have different expectations.

Many foresters see JFM primarily as a means to ensure forest regeneration. Communities tend to see JFM as a solution to the growing shortage of biomass, a means to ensure daily requirements of fuel, fodder, food, and other non timber forest products (NTFPs) and/or a way to increase income (Tewari and Campbell 1997). Within individual communities, gender, caste, class, and occupational perspectives also influence perceptions of JFM. NGO activists tend to support JFM as a vehicle for grassroots empowerment, whereas environmentalists favor JFM as a means for ecological revival. The perceptions of other stakeholders may also vary widely (Saigal 2000). This difference in perception and expectation often leads to conflicts over the rights and responsibilities of different stakeholders and the objectives of forest management and silvicultural treatments. As neither the community nor the FD is a homogenous group, a number of conflicts are also emerging within them (Sarin 1993, 1996).

Conflicts also arise due to multifarious and often conflicting functions Forest Department (FD) have to perform. This dichotomy between the FDs' internal culture and their new role leads to many internal conflicts. Many enthusiastic and dynamic officers and staff members get demoralized due to this and start viewing JFM as yet another "scheme." Another linked problem is that of the unsympathetic attitude of some senior officials toward JFM as they see it as a step toward dilution of their powers. They do not openly oppose JFM, but continue to send contrary signals to their juniors, creating confusion in the minds of field staff. The state forest departments also should also initiate planning process to guide internal organizational transformation and rationalization. Local communities should also be able to learn new ideas and techniques. Capacities must be created to develop consensus, transperancy, equity and individual tendency to free ride over nature. JFM requires a shift in attitude as well as new skills in extension, institution building, participatory planning, multiproduct management, conflict resolution, and marketing. These skills are not imparted at the time of training (Saigal 2000).

13.8 Applicability of Scientific Development and Research

The scientific community is now confronted by a twofold responsibility: first, to search and develop new science and technologies appropriate for rural people to raise their productivity; and second, to diffuse and propagate scientific and technological knowledge, thus fostering and training environment-friendly entrepreneurship among rural people, particularly young men and women (Table 13.3).

Well-designed cultivation systems coupled with adequate processing, distribution and sales lend themselves to commercialization and development opportunities will have to take into account the viability of strategic micro-enterprises. Advances in the technologies critical to forest production, management, and engineering, as well as forest products manufacturing, will sustain the jobs and economic health of rural communities while promoting the environment enjoyed by urban communities. The rural poverty can be eliminated by raising sustainable production. This can be done by focusing on diversified commodity production, exploiting local resources of comparative advantage and by disseminating highly efficient and environment-friendly agricultural, silvicultural and industrial technologies. Environment, education, family planning and so forth, however important but it is not realistic to expect people struggling to survive to be concerned about future generations and about conserving nature for sustainable development. Adoption of any technology by farmers largely depends on demonstration and training, transfer of knowledge, awareness generated and level of strengthening of capacity (Somanathan et al. 2006)

The more controversial aspects relate to socio-economic implications, understanding beneficiaries' goals and constraints and the policy and institutional background. Institutional backgrounds can affect, for instance, the sustained supplies of planting materials, an essential component of cultivation system. Similarly, a favourable policy environment with government support can help greatly (Mansuri

Table 13.3 Applicability of scientific development and forestry research

Technology options	Economic[a] efficiency	Ecological[a] sustainability	Social[a] equity
Nursery operations – plantations, and plant protection	9	10	8
Use of chemical fertilizer and pesticide in farmland	8	1	8
Soil and water management	8	10	8
Biotechnology for adapting plants to a specific location	8	10	6
Tissue culture research	8	10	6
Collecting planting material from the wild for cultivation	8	9	8
Gathering raw material from the wild	8	2	8
Cultivation of bamboo, rattan and other economically important species	8	8	10
Cultivation of energy other domestically important species	9	9	10
Creation of fiber farms	5	9	8
Dissemination of knowledge – farmland and industry	3	10	10

Source: Fieldwork
[a]On a 1 (low) to 10 (high) scale

and Rao 2004). Cultivation can readily reduce unwanted heterogeneity and provide better and more controllable harvesting and better quality products. Cultivation can readily be adapted to improve quality and quantity through specific agronomic treatments allowing better control of the cost of products than in the case of wild-collected material where availability; quality and yield are unpredictable (Cernea 1987). The major technology needed is the cultivation of priority species as the only major alternative to harvesting plants from the wild. It is an integral tenet of farm and social forestry where the least controversial aspect is the biological and agronomic practices. Essentially, the basic principle is to identify useful species suitable for a range of soils and ecologies, develop suitable propagating systems and cultivate the plants in suitable systems. Much of this is low-key research based on traditional resource management practices and local knowledge (Ramakrishnan 1992).

13.9 Unmanaged Forest

Once the land comes under the management of the Forest Department, then it is totally the responsibility of forest Department to take care of forest land. It becomes a forest offence for the local people to enter that area without the permission of the forest officer. The Forest department does not have connection at the local level.

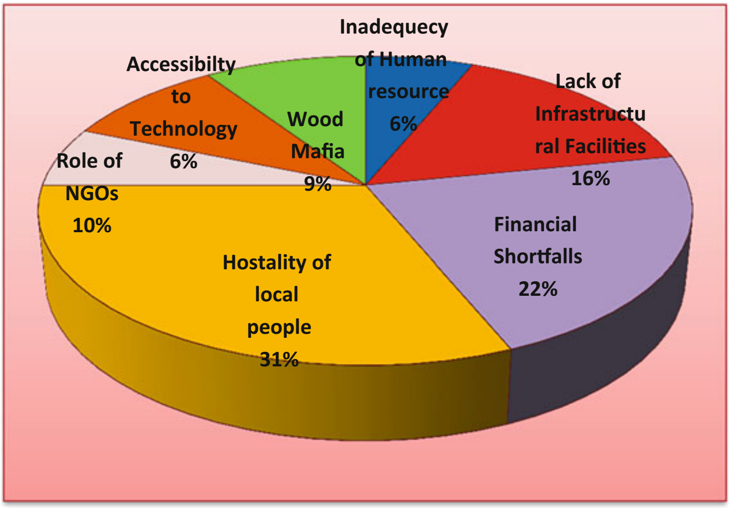

Fig. 13.3 Problems faced by forest officials

They are fully dependent on the information and help of block development officer who in turns is dependent on the village headman for the information of village problems. The visits to villages by these officers are rare making headman powerful and having monopoly over the local people in most of the cases. Over 40 % of the officials cited financial shortfall and lack of infrastructural facilities as other two major problems which they face (Fig. 13.3).

Forest officials cited many problems which they faced during the process of forest management. Hostility of villagers is the major problems at the ground level. In Uttarakhand, NGOs and civil society groups have historically played a strong advocacy role. Chipko, for example, was triggered by protests led by the NGO, Dasholi Gram Swaraj Mandal. Today, the NGO movement is split into different camps and factions. The vast majority have been co-opted to work as 'private service providers' for the several donor funded projects in the region, including the forestry project. Once they have accepted working on project terms, they effectively lose their critical and questioning voice. The overall impact is that today the NGO and civil society movements have been considerably weakened with hardly any concerted public action for protecting people's forest rights of forest data with local community demands has not progressed much in the valley.

Forest ranges administratively fall under the development block, still there is no systematic co-ordination between the development officer and forest rangers in a development block. This has created a vacuum in the administration, which has lead to increase in the smuggling activities in the valley and corruption among forest officials and headman. The study also informs us the continuous dependence of local community on surrounding forest and the need to address this issue in any forest management strategy. A project related to forest conservation and regeneration has to be of long gestation period to deliver the results of plantations and related activities.

13.10 Analysing Forest Management

Forests are managed for multiplicity of purposes. The multi-purposes of forest management are generally protection, conservation, production, scientific research and development, and environmental. While managing a forest area block, all such purposes cannot be equally synchronised. One purpose has to take precedence over other. The multiple objectives have to be prioritized and integrated as one main objective. This aim should be dynamic changing with requirements of forestry sector as well as of the people living in rural and urban areas. As seen in the study, till today the main objective of forest management plan is – timber exploitation. With so many years of planning and management of forest, forests in the valley are degrading. The non-parametric test of chi square has been performed to analyse the responses given by the forest officials.

It was assumed that responses of forestry staff would be uniformly distributed across different response categories because all of them follow the same procedures, rules and regulations of forest management and JFM. Chi-squared goodness-of-fit tests were used to examine whether responses of forestry staff differed across the various response categories, at the 5 % significance level. The response categories chosen for factors of success and failure of Forest management were: AG: Agree, ASE: Agree to some extent; N: Neutral and DA: Disagree. The assigning importance weights to response categories has also been done in descending order of importance (AG: 4, ASE: 3, N: 2, and DA: 1). For each question, the number of respondents assigning each particular importance level were multiplied by the corresponding weights and these were summed to obtain the total score.

The responses of forestry staff about possible factors of total quality forest management for each variable are placed into four categories. The following hypotheses have been tested-

- H0: The responses of forestry staff are uniformly distributed between response categories (AG, ASE, CS and DA) for each response variable.
- H1: The responses of forestry staff are not uniformly distributed between response categories for each response variable

The analysis of forest official indicates many factors that have led to the failure of forest management in the valley. The X^2 values allow the null hypotheses to be rejected in all cases and lead to the conclusion that the distribution of the views between forestry staff is not uniformly oriented across importance categories (Table 13.4).

Based on scores, the 'communication gap' is considered to be the most important factor leading to failure of forest management in the valley, followed by 'non-involvement of women' and 'unemployment'. These are followed by 'inter–village

Table 13.4 Factors for failure of forest management

Factors	Responses[a]				Goodness of Fit			Scores
	AG	ASE	N	DA	X^2	df	p	
Overlopping	27	22	14	17	4.900	3	0.179	219
Overgrazing	34	21	14	11	15.700	3	0.001	249
Communication gap	56	12	5	7	87.700	3	0.000	277
Illiteracy	29	35	5	11	30.600	3	0.000	242
Non - involvement of women	39	28	6	7	39.500	3	0.000	259
Caste structure	33	10	19	18	13.700	3	0.003	218
Poverty	32	21	12	15	11.700	3	0.008	230
Landlessness	33	19	12	16	12.500	3	0.006	229
Political interference	21	27	3	29	21.000	3	0.000	200
Scarcity of grazing areas	23	29	2	26	22.500	3	0.000	211
Inter village disputes	37	25	9	9	27.800	3	0.000	250
Unemployment	37	28	9	6	33.500	3	0.000	256
Wood smuggling	28	21	15	16	5.300	3	0.151	221
Silviculture practices	17	25	4	34	24.300	3	0.000	189

Source: Analysis of goodness of fit based on primary survey
[a]*AG* agree, *ASE* agree to some extent, *N* neutral, *DA* disagree

dispute', 'over grazing' and 'illiteracy' respectively. In this context, the use of a statistical inference technique is valid. Most of the officials cited communication gaps as major factors for the failure of forest management, but their views are not uniformly distributed as X^2 value is very high. The failure can arise from difference in opinion between local people and foresters. Communication is hampered by the seemingly broad and often inconsistent nature of central agency directives (unilateral top-down approaches). Physical distance (which hampers the frequency and depth of communication) and social distance (e.g., differences in the background and experience of top hierarchy and field staff of Forest Department resulting in elitism and language barriers) also hamper communication (Sood and Gupta 2007). Women which are the backbone of hill economy are totally ignored while preparing micro plans for villages. They have more information about the resource than their male contra part. Historically, also they are the one who had started all the major movements to save the trees or environment or actively participating in save the seeds movement or anti liquor movement in the Uttarakhand so non – involvement of women is major setback for the for joint forest management. The loss or further degradation leads to dislocation of people (www.iufro.org/science/task-forces/forest-people).

The analysis of different responses on factors for total quality management of forest areas indicates many important factors yet to be taken into consideration for sustainable yield or for sustainable forest management. The X^2 values allow again on the total quality management of forest resources rejected the null hypotheses in all cases and lead to the conclusion that the distribution of the views between forestry staff is not uniformly oriented across importance categories. Based on scores, 'community participation' is considered by foresters to be the most important factor for achieving successful implementation for total quality forest management, followed by 'forest degradation'. The forest officials do recognise that forest degradation is still taking place. These are followed by 'energy alternatives', 'harvesting of NWFPs' and 'employment opportunities' respectively. Similar cases can be seen even at the world level e.g. industrial groups like Mattel, are under pressure to use recycled papers (www.bbc.co.uk/programmes/p00knchf).

Granting rights to use forest resources scored least as most of the officials still think that it will lead to degradation of the resource. Due to this attitude of forest officials it very difficult to reduce the communication gap between locals and the department. Therefore, training and workshops are very much needed to make people aware about their rights and responsibilities as well as making forest officials to understand better the social and cultural requirements of a particular community. This consequently allow communities, local authorities and other supporting institutions to gain experience, new skills and confidence. Reducing communication gap and active involvement of local people is the solution leading to sustainable forest management in the valley (Table 13.5).

The degraded forests are required to be tackled for rehabilitation work on war footing so that the process of soil depletion can be checked and sustainable utilization of forest products can be part of regular forestry practices. The survey also indicates that local people know that there exist the problem of degradation and it need to be worked upon.

The forest officials are also aware that people do understand the problems related with forest resource. Again chi square test analysis shows that their responses are not uniformly distributed across different categories. More than 56 % of the forest officials think that local people are highly aware about forest degradation, while

Table 13.5 Factors for total quality management

	Responses[a]				Goodness of fit			
Factors	AG	ASE	N	DA	X^2	df	p	Scores
Forest degradation	45	12	10	13	41.900	3	0.000	249
Energy alternatives	38	20	14	8	25.200	3	0.000	248
Subsidies for fodder	31	19	11	19	10.200	3	0.017	222
Harvesting of NWFPs	38	19	13	10	23.700	3	0.000	245
Availability of funds	39	11	17	13	25.000	3	0.000	236
Community participation	42	21	8	9	37.500	3	0.000	256
Awareness & workshops	27	24	16	13	6.500	3	0.090	225
Frequent meeting with JFM members	36	19	13	12	18.500	3	0.000	239
Employment opportunities	34	25	11	10	20.100	3	0.000	243
Granting right for forest use	19	25	10	26	8.100	3	0.044	197

Source: Analysis of goodness of fit based on primary survey
[a]*AG* agree, *ASE* agree to some extent, *N* neutral, *DA* disagree

Table 13.6 Responses of forest officials about level of awareness among people

	Responses			Goodness of fit		
Issues	high	medium	Low	X^2	df	p
Level of degradation	45	23	12	21.175	2	0.000
Need for forest improvements	56	17	7	50.275	2	0.000

Source: Analysis of goodness of fit based on primary survey

70 % think that there is need for forest improvements. Fifteen per cent of the official responded that local people are less aware about forest degradation and more than 8 % think that local; people do not need improvement in forest conditions. This analysis indicates that there is not much gap in the understanding of the problem only thing required is to remove communication barriers so that things should become transparent both ways (Table 13.6).

The primary aim of the forest officials is to have power, authority, security, and facilities. The majority of staff considers increasing the legal authority in dealing with people to be a better option, which indicates lack of inertia for change of functioning and management style, and implies that staff is still oriented towards their bureaucratic role (Sood and Gupta 2007). Forests are owned and managed by government. Therefore, forest ownership is public in nature. Public ownership of forest enjoins upon government a responsibility to manage forest in such a way that it maximizes generation of public goods. With the introduction of New Forest Policy, a new era dawned in the forestry sector. Forest management focused on conservation of forest resources with the help of community participation as part of the Joint Forest management policy of the government. Although, there are many problems with this policy but it proved the commitment of government to give right to local people of forest resources. A right based approach to development is need of the hours The International Alliance of indigenous people even demanded rectification in the UN draft declaration on the rights of indigenous people (www.international-alliance.org/documents).

There is also a need for special efforts to attract more women into the forest departments, especially at the field level. A number of problems arise within the Forest Department because organisational changes have not kept pace with the changes in forest management objectives. Forest Department continue to be a hierarchical, centralised, top-down bureaucracies where instructions flow from top to bottom and only compliance information flows back. The entire system is control-oriented, and deviations from set norms are not allowed. There is a need to actively promote a participatory culture in the Forest Department also.

13.11 Concluding Comment

The forest policies are evolving at various stages and at various levels, but they need further strengthening and legal support. The forest policy should guide development of the forest sector and provide a clear indication of the state's goals for community forestry. The settlement process and expropriation of forest is a significant factor contributing to the deep resentment among forest dwellers and the people who are fully dependent on these resources. The concept of JFM is a central feature of the National Policy of 1988. It has been endorsed and initiated by all the states but there have been no accompanying changes in the national legal framework to implement it. It is operational through administrative orders and circulars, although it has been linked to state legislation in Uttarakhand. Moreover many programmes, so many policies make people more confused with the whole administrative structure. Traditional community institution like van panchayat can break down in the face of economic change, and external pressure on forest. In villages in which traditional system of management is still prevalent, they are often reluctant to share the management of forest resources with the forest department. The focus should to develop a model in which communities in collaboration with panchayats assume responsibility for micro planning, implementation, harvesting and conservation for forest areas. Although JFM on many counts has been successful in fostering forest conservation but it is rigid in terms of addressing social and institutional conditions across different communities.

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Chapter 14
Organic Agriculture from the Perspective of Small Farmers' Livelihood Strategies: Two Cases from Central and South India

Rie Makita

Abstract Although organic agriculture has been studied as a livelihood and an intervention for small farmers, it has rarely been analyzed within their overall livelihood strategies. This article explores how small farmers' livelihood strategies influence their perceptions of organic agriculture, focusing on the interactions of organic farming with other livelihood options. The analysis draws on two case studies of two projects run by a non-governmental organization aiming to convert small farmers in India into certified organic farmers. In the first case, the ecological and economic values of organic agriculture suited the livelihood strategy of subsistence farmers. However, this perception was applied not to the production of an exportable crop, coffee, but to the production of a variety of crops. In the second case, where small farmers were concerned with a specific cash crop, cotton, they put more emphasis on the economic value of organic agriculture. Such a perception of organic agriculture eventually led them to prefer conventional farming. In both cases, the interactions with other livelihood options made small farmers' organic agriculture unsuitable for export purposes. The form of organic agriculture practiced by small farmers may not be linked with organic markets in the global North.

Keywords Organic agriculture • Small farmers • Livelihood options • Coffee • Cotton

14.1 Introduction

Organic agriculture is a global movement that is well-known for not only environmental but also economic and social sustainability. The organic movement that started in the global North also opened up opportunities for products from Southern agricultural producers to find new markets in the North (Raynolds 2004). Many small and marginal farmers in the South are traditionally organic, depending on locally available manures; conventional smallholders whose yields are

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comparatively low can increase yields significantly by transitioning to organic production (Bacon et al. 2008: 353). Their disadvantages – small-scale production and unsophisticated technologies – may actually become a positive sales point within the global organic movement. Organic agriculture in Asia is, in reality, a small holder-oriented endeavor: India, for example, classifies 81 % of its farmers as small (IFAD 2005: 2). On the premise that there are two different kinds of organic farming: certified organic "producing for a premium price market" and non-certified organic "producing for their own households and for local markets" (IFAD 2005: 2), with a sizable acreage being under the latter kind of organic cultivation, India has tremendous potential to emerge as a major supplier in the world's organic market (Thapa and Tripathy 2006).

Despite the potential benefits of organic agriculture for Southern producers, in reality it is not easy for them to benefit from organic agriculture. Preceding social science studies on organic agriculture in the global South tended to focus on constraints in conversion from conventional or traditional (non-certified) organics to certified organics (Eernstman and Wals 2009; Thavat 2011; Thiers 2005). During the conversion period, many farmers cannot survive low yields and decreased income (Eyhorn 2007: 141–144). Even after they are certified, smallholders face further constraints in entering into competitive organic markets (Blanc and Kledal 2012). As a result, marginal and small farmers are less successful than large farmers in accessing organic certification (Bray et al. 2002: 442; Gomez Tovar et al. 2005). To remove or alleviate these constraints, some authors suggested and examined possible ideas, including combination with other ethical certifications such as Fairtrade (e.g., Browne et al. 2000), participatory guarantee systems (Nelson et al. 2010; Lyons et al. 2013), organic contract farming (Bolwig et al. 2009) and the provision of more governmental support to organic development (Twarog 2013).

Although organic farming has been studied as a livelihood and an intervention, it has rarely been analyzed within farmers' overall livelihood strategies. As IFAD (2005: 2) points out, the distinction between certified and non-certified organics is "sometimes blurred" because small farmers "straddle the two categories or sometimes slide between them from year to year" with their livelihood strategies. Although organic certification tends to simplify its "operational meaning toward a single variable: allowable versus prohibited inputs in organics" (Jaffee and Howard 2010: 397), farmers may interpret the original purpose of this initiative in different ways. Organic agriculture has many aspects, as indicated by the following definition given by the International Federation of Organic Agriculture Movements (IFOAM 2014):

> Organic agriculture is a production system that sustains the health of soils, ecosystems and people. It relies on ecological processes, biodiversity and cycles adapted to local conditions, rather than the use of inputs with adverse effects. Organic agriculture combines tradition, innovation and science to benefit the shared environment and promote fair relationships and a good quality of life for all involved.

When organic agriculture is used as a means of poverty alleviation, it is not plausible for small farmers to consider all the aspects of this holistic production system. To what strands they attach importance seems to depend on what livelihood strategy each farmer adopts by combining both farming and non-farming livelihoods. Without understanding such livelihood strategies, it is impossible to successfully use organic agriculture as an intervention.

In this article, I attempt to explore how small farmers' livelihood strategies influence their way of evaluating organic agriculture, on the basis of two case studies of two projects run by a non-governmental organization (NGO) aiming to convert small farmers in India into certified organic farmers (Makita 2011, 2012). In both projects, organic agriculture was compared with other livelihood options respectively. In the first project, small farmers organized in the state of Kerala were encouraged to pursue, in parallel, Fairtrade certification with a traditional local cash crop, coffee. Although Fairtrade coffee was chosen to make the participating farmers perceive a tangible benefit of organic farming, it ironically worked as a different livelihood option. In the second project, small cotton farmers organized in the state of Andhra Pradesh were confronted with genetically modified (GM) cotton seeds that are banned under organic certification. Organic cotton production therefore had to compete with conventional cotton production with GM seeds. In these two case studies, the analysis focuses on how these livelihood options interact with organic farming. Such interactions reveal how small farmers actually perceive organic agriculture within their overall livelihood strategies.

14.2 Interactions with Fairtrade Coffee: A Case from Kerala

14.2.1 Outline of the NGO Project

The project aimed to organize an association of small farmers who own fewer than five acres in highland Kerala in South India. The goal of the small farmers' association was to export their certified crops to foreign organic markets. When I first visited the project site in November 2008, it had been only 7 months since the official establishment of the small farmers' association, whereas the NGO had spent more than 2 years motivating and mobilizing small and marginal farmers. About 10 to 15 farmers composed one group; 52 groups had already been formed. A majority of members were below the national poverty line. Member farmers cultivated a wide range of crops, including coffee, rubber, cocoa, pepper, ginger, nutmeg, tapioca, and bananas, in small plots of steep land.

For the purpose of obtaining a group organic certification, the NGO introduced a liquid bio-fertilizer to members. At the start of the project, some members depended on chemical fertilizers, whereas some were traditionally organic farmers relying only on cow dung, litter, and crop residues. The bio-fertilizer introduced was effective not only as a substitute for chemicals but also as a supplement to traditional manures. It was expected to cure the diseases of some crops as well as to increase productivity at a cost lower than that of chemicals. The bio-fertilizer selected by the NGO was the ready-for-use liquid one, which was easiest to prepare at the farm level. Unlike other organic manures, the liquid bio-fertilizer was easily absorbed by plants and therefore gave instant results (Dhavse 2004). An appointed member took charge of mixing compost, liquid manure, bio-manure powder, sugar, and water in a special refiner, which was also supplied through the NGO. The completely concentrated bio-fertilizer was then distributed to each member. Member farmers had only to dilute the liquid with water before applying it to crops within 24 hours.

To organize small farmers into groups and reinforce organized groups, the NGO also provided other forms of technical and financial assistance for the farmers' association. Members received extension services in organic farming, which was rarely expected from governmental offices because of the limited numbers of field officers. Through the NGO, member farmers were able to readily collect information relevant to organic farming: for instance, details of government subsidies for the purchase of organic inputs. Most important, the NGO helped each group to open a group savings account with a commercial bank. Through this group account, members were expected to access bank loans for their own investment purposes in the future. This scheme was beneficial for many small farmers who were not able to individually access formal loans due to the lack of formal land titles.[1]

14.2.2 Another Livelihood Option

Becoming completely organic is a long process. Only after obtaining organic certification are member farmers allowed to sell their products on organic markets. The NGO considered it necessary to give member farmers some tangible benefit from being organic even during the transitional period and therefore decided to pursue the Fairtrade label for coffee from member farmers. Coffee, which is a major Fairtrade item, had traditionally been a cash crop in highland Kerala. To show the potential of Fairtrade coffee, the NGO began to purchase fresh ripe coffee berries from members at a higher-than-market price. The NGO also nurtured seedlings of a specific variety suitable for the selected processing method and distributed them to member farmers at a subsidized price.[2] Furthermore, a large drying space and a primary processing unit were built on the project site. There was even another plan

[1] Many of the association members were from a "scheduled tribe" who had only possession rights to their land (see Kjosavik and Shanmugaratnam 2007).

[2] Concerning some coffee varieties, the speed of ripening differs among berries on a bush, which makes it difficult for farmers to pick out only ripe berries after harvest, but if they wait until all berries are ripe, some are rotten by then. Therefore, the project introduced a specific variety whose berries ripened evenly.

to build a processing factory near Cochin (a major port city in South India) for the production of final coffee products for export.

For small farmers, practicing organic farming on their farms and producing coffee for Fairtrade markets are two different things. In practicing organic farming, farmers need to consider the nature of organic on their entire farmland rather than to increase the production of a specific organic crop. However, if they pursue Fairtrade certification, they are inevitably required to pay special attention to a selected crop by which Fairtrade is certified. Although the project aimed at Fairtrade–organic double certification, Fairtrade certification did not require certified products to be completely organic. For most member farmers who had long planted coffee on their plots of land, coffee production for the future Fairtrade market emerged as a new income-generating opportunity. Contrary to the NGO's expectations, member farmers regarded this new opportunity not as complementary to organic farming but as another livelihood opportunity different from organic farming.

14.2.3 Farmers' Reactions to Organic Agriculture

My field study focused on one group consisting of 13 member households who were neighbors in a village. Focusing on one group enabled me to observe their livelihood strategies closely. The 13 members reacted to organic farming and coffee production for Fiartrade certification in different ways. Their reactions can be classified into four categories: A. preferring organic farming to Fairtrade coffee production; B. preferring Fairtrade coffee production to organic farming; C. making organic farming and Fairtrade coffee production compatible; and D. being uninterested in either.

Seven members, falling into Category A, were full-time subsistence farmers and agricultural laborers-cum-farmers. They appreciated the project's interventions in organic farming but were not interested in Fairtrade coffee. In other words, these farmers regarded Fairtrade coffee production as neither a complementary nor a competing livelihood option. The objective of the subsistence farmers was to maintain their modest living. Therefore, they gave priority to ensuring an income throughout a year rather than to maximizing annual income. The small and marginal farmers were planting a variety of crops with different harvest periods. Cocoa was one of their preferred crops, which were harvested and sold once a week throughout the year. One of the marginal members, owning only 0.5 acres in total, properly expressed his ambivalence:

> It is attractive to sell coffee to the project at the higher-than-market price, but in such tiny plots of my land, there is no more space for increasing coffee bushes. Coffee brings income only once a year. I do not want to decrease space for other crops. (Makita 2011: 211)

For these subsistence farmers, diversification of crops was more important than diversification of sales channels. Biodiversity – a principle of organic agriculture – fitted with their livelihood strategy. They also welcomed the new organic method introduced by the project. The subsistence farmers were not so keen on investing in agriculture, that is, increasing production with chemicals, but nor were they satisfied with traditional natural farming. For them, the new organic method was a way of improving their farming at a small cost.

The laborer-cum-farmer members, who were busier and poorer than full-time farmers, tended to use more chemicals than did the full-time subsistence farmers because they needed to save time and to maximize production. As soon as the bio-fertilizer was introduced, they switched to this organic fertilizer. In addition to the cheaper cost of the bio-fertilizer and its easy preparation, one of them described another merit of the bio-fertilizer as follows:

> When I apply chemical fertilizer, I have to carefully measure a proper quantity for each crop. In applying this bio-fertilizer, I do not have to be nervous. I can use this for all crops. It does not damage crops even if I apply too much. (Makita 2011: 214)

In sum, the members adopted the introduced bio-fertilizer because it suited their part-time *extensive* farming.

In the same group, contrary to the first category, three members hesitated to switch from conventional to organic farming (Category B). They were part-time farmers with higher standards of living. It was typical of busy part-time farmers to prefer chemical to organic fertilizers. The three members were not exceptional. When the project introduced the new bio-fertilizer, its easy preparation immediately attracted them. However, they gradually found it inconvenient to use this liquid fertilizer. A quantity of the bio-fertilizer, adequate for the capacity of the refiner, was produced on fixed dates. The wife of one of the three, who ran a small cafeteria in the village, missed the latest opportunity to buy the bio-fertilizer:

> We were informed beforehand of the production schedule. But on the day, my husband worked in the town all the day (as a load carrier) and I also had to go out of the village. Even if I could buy, I was not able to find time to apply the liquid within 24 hours after the purchase. I wish I could buy and apply it whenever I like. (Makita 2011: 214)

It was difficult for the busy part-time farmers to comply with the project's bio-fertilizer production schedule. Because they had already diversified their income sources, they were less concerned about further diversification in one of the sources, farming, than the subsistence farmers in Category A.

Whereas the three members in Category B consequently used the bio-fertilizer less frequently, they were attracted by Fairtrade coffee. Although their non-farm income was larger than their farm income, all of them intended to keep farming their own land as a basic asset. Their concern in farming was to maximize profits for the smallest possible investment of time. For these families, it was convenient to sell fresh coffee berries to the project without any post-harvest activities. They appreciated the better price offered by the project and they were able to save time and transport costs which they would otherwise incur. Fairtrade coffee production was a more suitable option than organic farming for the livelihood strategy of these members.

Only one member, called KJ, was categorized as C. Under his livelihood strategy, organic farming and Fairtrade coffee production did not compete with each other. Although KJ was officially a small farmer, owning three acres of farmland, his family customarily encroached on and used more than 20 acres of forestland for coffee cultivation. This unofficially occupied land had brought large profits to this family for the past 20 years. Although coffee cultivated in the forestland was completely organic, it was impossible to obtain individual certification for the *unregistered* land. To obtain a group organic certification, KJ was therefore keen to facilitate other members to adopt the new organic method. KJ's family willingly offered a part of their homestead and a supply of electricity to the farmers' association so that a refiner for the bio-fertilizer could be operated there. KJ also showed a great interest in selling part of his coffee to the Fairtrade market. Being typical of large-scale producers, he attempted to sell coffee at higher prices as well as to diversify his sales channels. Unlike other small farmers, who tended to sell coffee berries immediately after harvest or primary processing, he stored dried berries for several months, waiting for the best timing. The two livelihood options created by the NGO project were compatible only under the livelihood strategy of this substantially large commercial farmer who could afford to diversify the sales of a single item – coffee in this case – by adding the organic and Fairtrade values to the item.

The remaining two members, poorer laborer-cum-farmer members, seemed indifferent to both the new organic method introduced by the project and the Fairtrade coffee (Category D). These two members tended to be absent from the group's regular meetings. They may have joined this group to maintain good relationships with the neighbors, who were also their employers. One of them, a female family head, confessed that even the bio-fertilizer was more costly than traditional manures. Although they did not really understand the concept of organic agriculture, they would benefit from group organic certification if they could continue their current traditionally organic farming.

14.2.4 Different Perceptions of Organic Agriculture

The case study in South India revealed that even a single group of smallholders comprised different stakeholders who had different livelihood strategies and thus reacted differently to organic agriculture. Their perceptions of organic agriculture appeared more clearly when Fairtrade coffee production was introduced as another livelihood option.

The majority of marginal and small farmers agreed to pursue organic certification, which covers any crop, whereas they were reluctant to pursue Fairtrade certification, which focused on a single crop. For them, diversification of crops was more important than diversification of sales channels. The organic initiative fulfilled subsistence farmers' wish to gain better profits throughout the year and to reduce costs of chemicals. In other words, their need for crop diversification coincided with a principle of organic agriculture, "biodiversity"; their need for the curtailment of production costs was realized by another principle, no "use of inputs with adverse effects" (see the definition in Sect. 14.1). The subsistence farmers expected to sell many other crops rather than Fairtrade coffee.

Conversely, the livelihood strategies of wealthier part-time farmers who did not have to consider crop diversification seriously did not harmonize with biodiversity. Although the other merit of organic farming, reduced production costs, was also attractive for them, the introduction of Fairtrade coffee nullified the merit of organic farming. The value of organic agriculture varies depending on each farmer's livelihood strategy. The existence of different strategies in a group is highly likely to make it difficult for member farmers to pursue a group organic certification.

14.3 Interactions with Genetically Modified Seeds: A Case from Andhra Pradesh

14.3.1 Outline of the Project

India is the second largest cotton producer and consumer in the world (Osakwe 2009). India, even though it has the largest area under cotton cultivation, is known for its low productivity because of severe pest ravages and its predominant cultivation under rain-fed conditions (Narayanadamoorthy and Kalamkar 2006: 2716; Eyhorn 2007: 24). The inevitable use of pesticides not only increases the financial burden on the farmers but also creates health hazards and environmental risks, and this financial burden is related to the high incidence of suicides among poor farmers in the cotton-growing areas (Patil 2002; Narayanadamoorthy and Kalamkar 2006: 2716). A countermeasure against the indiscriminate use of pesticides is organic cultivation. Although organic cotton accounts for only 1.1 % of global cotton production (as of 2009–2010), it has steadily increased in recent years (Truscott et al. 2010).

The same NGO supported the formation of an association of cotton farmers in the state of Andhra Pradesh (AP), one of the three major cotton-producing states in India. The NGO started its cotton project with the following vision: "to increase the power, negotiating position and knowledge base of small and marginal farmers in India by eradicating exploitation in agricultural production and supply chains, and by mainstreaming the farmers [into the] economic prosperity of the country" (taken from the NGO's project document). Their project used organic farming as a means of poverty reduction. The NGO provided the association's members with technical assistance in organic cotton production and attempted to link the association with organic markets in the global North.

The district in AP chosen by the project was known for the high incidence of suicide among cotton farmers living there. When I first visited the project site in December 2010, about 2700 small farmers had been organized primarily for the purpose of obtaining organic certification. According to the NGO's record, the members' average landholding was 4.6 acres for 2010–2011. The livelihoods of farmers depended solely on rain-fed farming in the district. The attempt to convert to organic farming began in 2006, and 1017 members had already survived the 3-year conversion period in December 2010.

14.3.2 Another Livelihood Option

Another measure which had potential to help the poor cotton farmers was genetically modified (GM) or *Bacillus thuringiensis* (Bt) hybrid seeds. Bt seeds have been introduced to increase cotton yields as well as to reduce the use of chemical inputs (see Tripp 2009). The introduction of Bt seeds has aroused vigorous controversy since the commercialization of the first Bt cotton varieties in 1990 (Baffes 2011: 3). On one hand, in addition to anti-GM organism movements (e.g., Herring 2005; Scoones 2008), there are authors who argue that Bt cotton may not be economically viable without accessible support services – input supplies, technical advice, and finance – and reliable output markets (Gouse et al. 2008) or in the long term because of the increased need for pesticides to cope with the emergence of secondary pests or the high levels of pest resistance to the Bt toxin (Dowd-Uribe and Bingen 2008). On the other, scientific and policy consensus regards GM crop technology as a "pro-poor" technology that contributes to agricultural and economic development (Scoones 2002; Glover 2010). In fact, the use of GM cotton seeds has spread rapidly in the global North and South, including India. In India only one company dealt with three Bt hybrids in 2002, but 35 companies had received approval to sell 522 Bt hybrids by 2009 (Choudhary and Gaur 2010: 16). Bt cotton was estimated to cover 86 % of the national cotton area in 2010 (Choudhary and Gaur 2011). As a result, the national average yield of cotton dramatically increased from 308 kg per hectare in 2001–2002 to 568 kg per hectare in the 2009–2010 season (Choudhary and Gaur 2010: 10). Although both merits (Ramasundarama et al. 2007; Subramanian and Qaim 2009, 2010; Qaim 2010) and demerits (Narayanadamoorthy and Kalamkar 2006; Morse et al. 2007; Lalitha et al. 2009) of Bt cotton are also pointed out in India, such a rapid spread suggests that, as Srinvas (2002) argues, technological and economic factors may have outweighed ecological concerns.

Cotton cultivation with Bt seeds is a 100 % competing option against organic cultivation because organic certifications clearly ban the use of GM seeds from the ecological viewpoint (IFOAM 2007). When organic farming is introduced to cotton farmers, their reactions to organic farming depend on how Bt cotton has affected small farmers. They regard Bt cotton in two ways: as a new technology and as a new cash crop. First, those who have been suffering from pest attacks with non-Bt seeds adopt Bt seeds as a newly introduced technology for alleviating the pest problem (Roy et al. 2007). Second, farmers who have no previous experience in cotton cultivation are attracted by the higher yields from Bt seeds and begin cotton cultivation with them (Stone 2007: 76). In response to the introduction of organic farming, farmers in the former group are required to make a decision as to whether or not they should switch from conventional farming with Bt seeds to organic farming with non-Bt seeds. Farmers in the second group have two options – conventional and organic – at the same time. Each farmer's experience before the project may influence his or her decision on the adoption of organic cotton cultivation.

14.3.3 Farmers' Reactions to Organic Agriculture

Primary data were collected in December 2010 and in February–March 2011, focusing on members living in one village (hereinafter, K village). This village was included in a cluster with the highest dependence on cotton. In K village, there were three groups consisting of 35 members in total (13, 13, and 9 members respectively). There were 341 households in this village.[3] All the households were regarded as below the national poverty line, and about half of them belonged to scheduled castes or tribes.[4] Although there were no statistical data about the villagers' economic activities, the villagers themselves agreed that there were more than 200 agricultural households cultivating cotton, about 100 households cultivating other crops only, and some landless households, equivalent to about 10 % of the village population. Therefore, the 35 members who had at least attempted organic cotton cultivation were a minority in this village. At the time of my fieldwork, under the project, 28 out of the 35 members had experienced the last three seasons of cotton cultivation; seven members had experienced two seasons only. Whereas two of the 35 members had already practiced organic cotton cultivation individually, 33 members started only after joining the association.

Even if most of the members were interested in organic cotton cultivation, they did not adopt organic practices all at once. As Table 14.1 shows, in the first season after joining the association, only 14 out of the 35 members cultivated all their cotton organically. Fifteen members cultivated part of their land organically, keeping the other parts under conventional tillage. This action came from their risk-averse strategy: they were afraid of reducing yield suddenly by full-scale conversion to organic. The remaining six members tried to cultivate at least part of their land organically at the beginning of the season, but could not restrain themselves from using chemical pesticides when insects increased in the rainy season.

As observed elsewhere (Eyhorn 2007), it was not easy for the members to survive low yields during the conversion period. Only eight members were able to continue organic cotton cultivation all the time after participation (see

[3] The number of total households was surveyed by the District Rural Development Agency in the year 2003–2004.

[4] This information is based on a survey conducted by the *mandal* revenue office in 2001. *Mandal* is the administrative unit below the district unit.

Table 14.1 Patterns of cotton cultivation by the focus group in the *first* season (K village, Andhra Pradesh)

Patterns	Description	Number of members
1	Organic with non-Bt seeds only	14
2	Organic with non-Bt seeds and conventional with Bt seeds in parallel	15
3	Conventional with Bt and non-Bt seeds	6
	Total	35

Source: Makita (2012: 1238)

Table 14.2 Patterns of change in cotton cultivation by the focus group (K village, Andhra Pradesh)

Patterns[a]	Description	Number of members
1-A	Continued organic only	8
1-B	From organic to both organic and conventional	3
1-C	From organic to conventional	3
2	Continued both organic and conventional	15
3-A	Continued conventional only	4
3-B	From conventional to both organic and conventional	2
3-C	From conventional to organic	0
	Total	35

Source: Makita (2012: 1238)
[a]The three patterns in Table 14.1 changed into six different patterns

Table 14.2). Some members again started to use Bt seeds with chemical inputs on part of their land, and some completely gave up organic cotton cultivation. Many of those who started to cultivate in both conventional and organic ways decreased the acreage for organic and increased that for conventional cultivation. Although two of the members who did not practice organic methods in the first season adopted organic methods in the second or third season (3-B in Table 14.2), the majority of members gradually lost interest in organic cotton cultivation. In other words, the majority of members chose the rival livelihood option, that is, conventional cotton cultivation with Bt seeds. Under these circumstances, it was impossible for the association to be certified as organic. The project was discontinued several months after my fieldwork without bringing organic certification to these farmers.

Many farmers in K village, both members and non-members, were not cognizant of the difference between Bt and non-Bt seeds. They started cotton farming only after official Bt seeds were released: local input-trading shops that had mushroomed for the last 3 or 4 years in the nearest town had dealt with Bt seeds only. It was physically difficult to buy non-Bt seeds. For the majority of farmers, except the association members, Bt seeds were synonymous with cotton seeds. A few farmers who had cultivated cotton for more than 10 years switched from non-Bt to Bt seeds simply because the local input shops changed their merchandise. Although most farmers recognized better yields from Bt seeds, they rarely had knowledge of GM organisms. As a result, those who participated in the project compared the two livelihood options – conventional cultivation with Bt seeds and organic cultivation with non-Bt seeds – only in terms of yield and production cost. There was no difference in terms of selling price during the conversion period.

For organic cotton cultivation, the NGO distributed non-Bt hybrid seeds only to members of the association. Membership of the association afforded the only opportunity to obtain non-Bt hybrid seeds in the locality. The project provided members with non-Bt seeds at the price of 435 rupees (Rs.) per packet, which was lower than the average retail price thanks to bulk purchase by the association. This price was also appealing to some non-member farmers who suffered from the high price of Bt seeds, which cost an average of Rs. 750 per packet. A few of the members confessed to me that they sometimes resold non-Bt seeds they had bought through the project to non-member neighbors to gain a small profit margin.[5] Contrary to the NGO's expectation, the lower cost of seeds did not work as an incentive for organic cultivation, unless they could sell their products at a higher price.

14.3.4 Different Perceptions of Organic Agriculture

Farmers' recognition of organic agriculture was binary: for food crops and for cash crops. Organic farming itself was nothing new, either to the association members or to non-member farmers in this locality. All the farmers I met, members and non-members alike, had never used chemical fertilizers on their farms before starting cotton cultivation. After cotton came to the village as a new cash crop, they began to apply chemical fertilizers only for cotton and red gram (pigeon pea) planted with cotton as a refuge crop in the same plot, while continuing to cultivate other food crops such as sorghum and vegetables organically.[6] Therefore, they had fully understood the ecological value and practical techniques of organic farming.

Concerning cash crops such as cotton, however, economic value was liable to surpass ecological value. The importance attached to economic value was more obvious in relation to leased-in land. Even members who adopted organic practices on their own land usually applied chemical inputs with Bt seeds on leased-in land. Such farmers gave priority to the maximization of profits from the leased-in land with more reliable technologies. A member living in K village explained his strategy:

> The lease period is one season. During the limited time I paid for, I want to harvest as much cotton as possible with Bt seeds. But on my own land, it is important to maintain the soil

[5] Non-members who obtained non-Bt seeds through members planted both Bt and non-Bt seeds together for conventional cultivation.

[6] "Cultivating nontoxic ... crops (refuges) in the proximity to transgenic crops that produce Bt toxins is widely recommended to delay pest adaptation to these toxins" (Vacher et al. 2004: 913).

fertility by organic farming. I will continue both conventional cultivation on leased-in land and organic cultivation on my own land. (Makita 2012: 1238)

Although organic farming was in general a traditional technology, organic *cotton* cultivation was a new technology introduced by the project. Although it is comparatively easy to show the economic benefit of Bt seeds, it is difficult to show the economic benefit of organic cotton without certification. At the time of the fieldwork, market prices for conventional cotton had been kept high, which allowed farmers to buy expensive Bt seeds and other inputs.[7] After their 3-year attempt at organic cotton cultivation, most of the members realized afresh that conventional farming with Bt seeds was the only option for profitable cotton cultivation. Ironically, their experience of organic cotton cultivation rather contributed to the further spread of Bt seeds. In this cotton project, the attempt of the organic initiative was neither simply to cease the use of chemical inputs nor to adopt organic methods but rather to compete with Bt seeds permeated as a reliable technology.

14.4 Conclusion

On the premise of a recently increasing shift from farm to non-farm activities in the rural South (e.g., Rigg 2006), when organic agriculture is given as a livelihood option, farmers may make decisions between farming and non-farming livelihoods (Thavat 2011). Furthermore, as the two case studies from India show, even within farming livelihoods, small farmers make decisions by comparing organic farming with other livelihood options. Small and marginal farmers' decisions on organic farming vary depending on their overall livelihood strategies. Without understanding their livelihood strategies, it is impossible to use organic farming as a means of poverty alleviation.

Attention to other livelihood options particularly reveals how small farmers evaluate organic agriculture. In the first case in Kerala, the introduction of Fairtrade coffee clarified the subsistence farmers' strategy, under which they wanted to diversify their crops as much as possible. This strategy seemed to suit organic agriculture, fostering biodiversity. In other words, the ecological and economic values of organic agriculture coincided with each other under the livelihood strategy of subsistence farmers. However, the failure of Fairtrade coffee, at the same time, suggests how difficult it is to help small farmers by using organic agriculture through certification for export purposes. In the second case in Andhra Pradesh, although small farmers understood both the ecological and economic values of organic agriculture, they obviously put emphasis on the economic value in the production of cash crops. If there is a more lucrative option, such as Bt cotton, organic agriculture easily becomes less attractive. The second case also suggests the

[7] Truscott et al. (2011) also note better prices for conventional cotton in India, which continued at least until June 2011, tempting contract growers to abandon organic cotton.

unsuitability of small farmers' organic agriculture for export purposes, in another sense. Only when they can gain better profits throughout a year and reduce costs for chemical inputs, can the organic initiative help small and marginal farmers. Such a form of organic agriculture may not necessarily be linked with organic markets in the global North.

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Chapter 15
Integrated Coastal Zone Management in North Kanara Coast

Ashok Kumar and Anju Singh

Abstracts Coastal environment contains diverse resources and productive habitats for human settlements. Local subsistence coastal zones have been among the most heavily utilized area because of their resources. The North Kanara coast has total geographic area of 10,291 km^2. About 0.2 million hectares of land in the study area is under agriculture and horticulture. The present study is based on 5 taluks out of total 11 taluks for better analysis. The database used for the study is mainly secondary. An extensive literature survey has also been done covering with various dimensions of resources of the coastal zone. The secondary data collected from several institutions has given a base for the research work. In North Kanara role of local people in the management is not significant, as most of the local people don't think that they are participating adequately in the management processes. The criticalities of the problems are not similar throughout the coast. Karwar has maximum length of coastline followed by Honavar, Kumta, Bhatkal and Ankola. The area under different coastal regulation zone in different talukas varies as well. The uneven spatial development along the coastal development has resulted variation in the potentiality and challenges for development. The integrated coastal zone management is needed for the coastal zone of North Kanara. The priority areas, which should be taken under consideration for the coastal zone management of North Kanara, are pollution control as the high pollution level is leading to emergence of a number of other problems and ultimately damaging the environmental health of coastal zone.

Keywords Coastal environment • Resources • Coastal regulation • Urbanization • Kanara coast • India

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15.1 Introduction

Coastal environment has an instrumental bearing over the economy of the nation. By virtue of its diverse and precious resources productive habitats, rich biodiversity and its locational advantage to many of the human activities. It contains diverse and productive habitats for human settlements, resource development and local subsistence coastal zones have been among the most heavily utilized area because of their resources. A wide variety of industrial and commercial activities are performed at the coastal zone such as power generation, mining, fishing, and drilling and so on. Human beings also harvest food from the coastal zone. Half of the productivity of the ocean of the world accessed along the coast and the estuaries, which makes the coast line most productive areas known on the earth.

Thus, the coastal zone is exposed to rapid urban growth, increasing population pressure, expansion of major industries, particularly tourism and extensive exploitation of marine resources (Patil and Bhatt 2006). The resource includes the population of marine and freshwater resources, air pollution, loss of marine and land resources, loss of cultural resources, loss of public access, soil degradation, and increasing levels of noise and congestion (UNEP 1995). To combat these problems many attempts have been made to protect the coastal zone, but they had only a partial success because they are largely being sectoral and there is fierce competition for coastal resources in many areas (Ministry of Environment and Forest 1991 and 2002). Therefore, a dire need of integrated coastal zone management has been felt by policy makers, environmentalists and resource managers and so on.

15.2 Study Area

North Kanara is located between 13°55′ to 15°32′ N latitude and 74°05′ to 75° 05′ E longitude. It is one of the biggest districts of Karnataka, with abundant natural resources. The district has varied geographical features with thick forest, perennial rivers and abundant flora and fauna and a long coastal line of about 140 km in length. It is surrounded by Belgaum district and state of Goa in the north, by Dharwar district in the east, by Shimoga and Udupi districts in the south. Arabian Sea forms the west border. Its total geographic area is 10,291 km^2. For better study, out of all 11 talukas of the districts, five talukas has been selected as the spatial unit of the study. Because remaining areas of the different talukas are far away from the coast, but still it per cent per cent has backward and forward linkages with coast. They are Karwar, Ankola, Kumta, Honavar and Bhatkal.

Topographically, the regions are divided into three distinct zones, the narrow coast, the abruptly rising hills, and the flatter, elevated eastern zone that merges with the Deccan Plateau (Nayak 1986). The coastal zone is the most thickly populated with a multitude of Coconut clad villages. And only about 0.2 million hectares of land (roughly about 10 %) is under agriculture and horticulture. The hill chains of the Western Ghats, which run in the north–south direction, parallel to the coast, form the backbone of the district. These hills, unlike the rest of the Western Ghats, seldom exceed 600 m. These are precipitous towards their western aspect. At several points in the district, the hills run right into the sea, interrupting the continuity of the sea beaches and providing ample rocky inter-tidal and sub-tidal habitats with their unique flora and fauna.

15.3 Research Methodology

The present paper is based on both Primary and Secondary data collection. Regarding data, an extensive literature survey has also been done covering with various dimensions of resources of the coastal zone, As far as secondary data is concerned the information collected from several institutions has given a base for the research work. For getting information about coastal issues and management, prior works of the other agencies or scholars has also consulted. The data has been suited and tabulated according to the need of the study. For analysis of the data, descriptive statistics has been used frequently. For presentation of the data, statistical and cartographic methods has been used in the form of tables, charts, pie diagrams, bar diagrams, line graphs and choropleths etc. however, selection of the above mentioned techniques have been made according to the nature of the available data and need of the study. The sketches of the various aspects of the coastal zones have been drawn using software named coral draw. Flow charts have been used to simplify the complex things in the course of the study. For spatial analysis the softwares such as Arc view and ERDAS Imagine has been used.

15.4 Results and Discussion

15.4.1 Role of Institutions in ICZM

Natural resource management is an interdisciplinary activity, where the representatives of the different disciplines work together, integrating their efforts into a comprehensive cohesive manner. The issue, problems and the opportunities are intermingled inclusively and have complicated interaction. Therefore, targeting any problem or making sustainable developmental plan for the coastal issues without taking into consideration of various elements of coastal ecosystem will not be justified. Hence, an integrated and comprehensive plan is needed for the sustainable coastal zone management. In this regard, a number of organization are working together to attend a common and ultimate goal i.e., sustainable coastal development with maximum benefit of human society and minimum disorder to the ecology. These organizations perform different responsibilities and functions under integrated coastal zone management.

For coastal zone management, every state has constituted a coastal zone management authority for the concerned states which comprise of a majority of government representatives especially from Department of Forest and Environment, Revenue, Town and Country Planning, Tourism, Industries, Urban Development, Commerce, Pollution Control Board, Fisheries and Public Works. Such amalgamation ensures sustainable development and integration of management plans at various levels.

Apart from governmental organizations, a number of self help groups, non-governmental organizations, local bodies and local people are also taking a decisive role in the coastal zone management. It is evident from the field investigation that government is leading institution to make any significant mark in coastal zone management, but this fact cannot be ignored any management plan cannot be successful without other institutions active participation.

According to the primary survey done in year 2011, the institutions most of the assistance has been done awareness programmes, as it is evidence from the response from the local people of the coastal zone. According to respondents about 56 % work done by coastal zone management authority over making people aware about the various issues. Apart from 28 % contributing in Training and technical assistance has also been given.

Thus, it can be inferred from above mentioned facts that the coastal zone management institutions have to go a long way to ensure sustainable development. It will have to diversify their role in the management plans. The kind of assistance in the coastal zone, which is being given at present, should be more diversified to build capacity to tackle complex issues (Fig. 15.1).

15.4.2 People Participation in Coastal Zone Management

Public participation is the fundamental aspect of ICZM. It provides an opportunity to the people to make their views known prior to the adoption of policy by government. Local knowledge may be instrument in dealing with the complex and locally prevalent problems. The proper utilization of resources depends upon the community's understanding of the delicate nature of these resources and the beneficial role of the proposed project in people's daily lives and future welfare (Mathbor 1997). Ensuring equitable access to, and harvesting of, marine and coastal resources can inspire the community to contribute activity in resource conservation some of the burden of information gathering, planning, routine management and enforcement can be shifted from central government. It may reduce the cost in the management planning. Long term conservation and development processes may be hampered in the absence of people's participation (Ramachandra and Ahalya 2000). Thus, the lack of proper participation of local people has resulted into the limited success of ICMZ in most part of the world.

In North Kanara role of local people in the coastal management is not significant, as most of the local people don't think that they are participating adequately in the

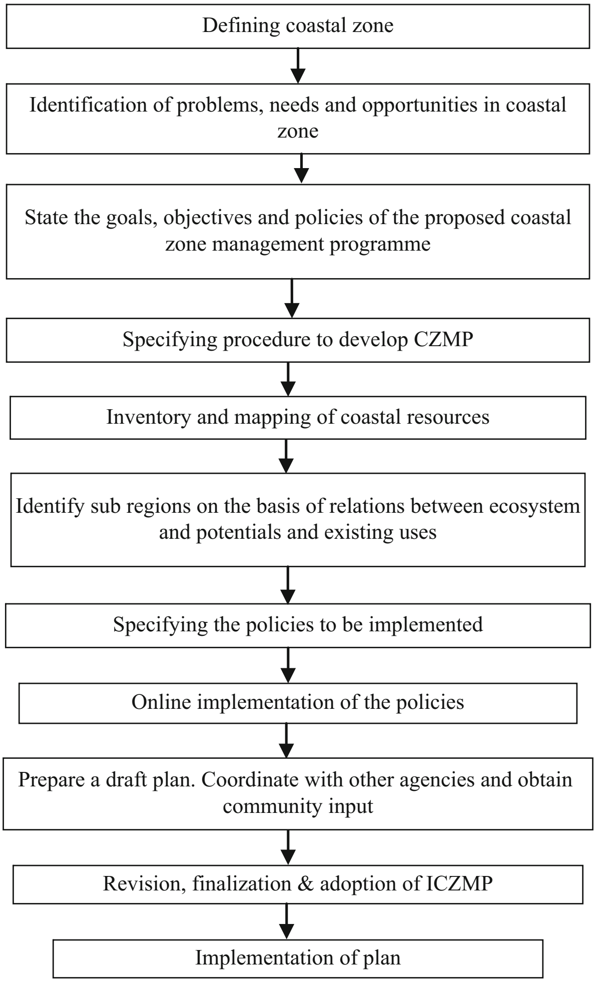


Fig. 15.1 Procedures for development of ICZM plan

management processes. Only 13 % of the respondents believe that local people can adequately contribute to ICZM. There are few reasons for their inadequate participation. First of all the level of awareness is one of the most important reasons for this. Fifty three per cent of the total interviewed respondents were not aware of the concept of ICZM. Even among the aware section of the people about one third respondents are unaware of CRZ regulations. This is the key in the management of any region the coastal zone (Figs. 15.2 and 15.3).

Secondly the government programmes have not been formulated in a way that people can participate in implementing them which ultimately leads to only partial success of the government programmes. This is evident from the fact that, the majority of the people 76.37 % are unaware of the programmes launched by government.

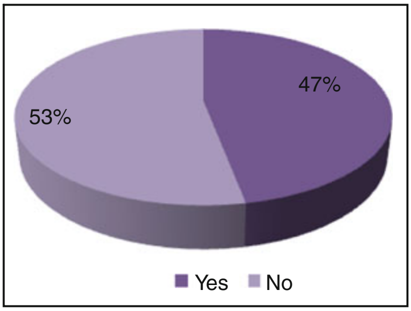


Fig. 15.2 Awareness about ICZM among people in coastal zone (Source: Primary Survey, 2011)

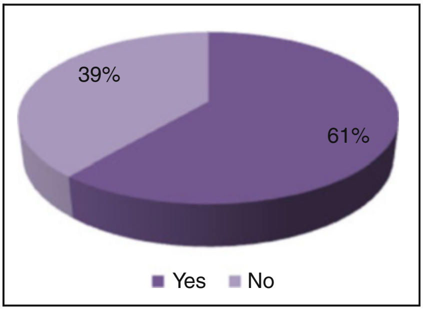


Fig. 15.3 Awareness about CRZ among people in coastal zone (Source: Primary Survey, 2011)

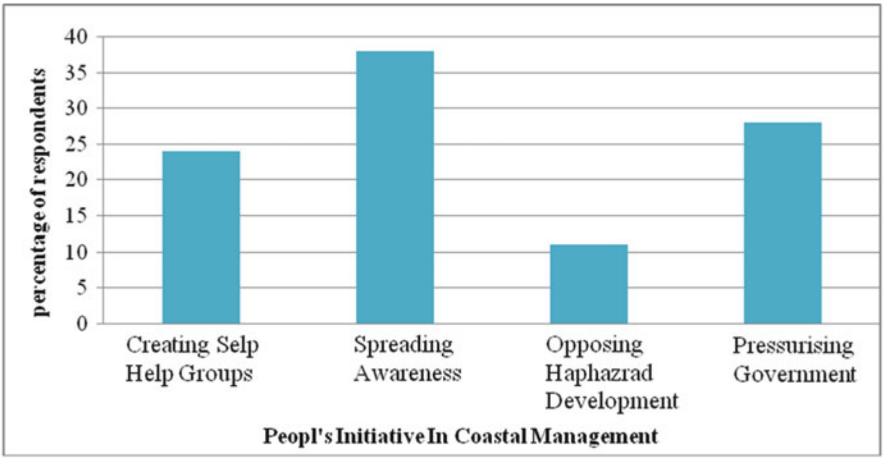


Fig. 15.4 Role of people in coastal zone management (Source: Primary survey, 2011)

The contribution done by the local people, is mainly in the form spreading awareness about the coastal issues which are emerging in the coastal zone of North Kanara (Fig. 15.4), followed by pressurizing for saving their environment from the unregulated development.

The creation of self help groups for their own benefits are another way of participation, but it is mainly initiated by NGOs. The involvement of the local bodies in the coastal zone management is also not very satisfactory. However, 64 % of the respondents of the total interviewed admit that local bodies are contributing adequately, but another dimension about the local contribution is telling different story which is antagonus to statistics. The role of local bodies especially in the rural areas are only limited in the awareness and mobilizing local people towards the coastal issues. Their role in the management planning and implementation plans are very limited. The bureaucratic stronghold is evident in most of the implementing works regarding the coastal zone management.

15.4.3 Spatial Aspects of Coastal Zone Management

The different areas of the coastal zone have different potentials and challenges. The criticalities of the problems are not similar throughout the coast. Therefore, the management strategies for the different places should be formulated according to the local conditions. The spatial unit for the present study is the taluka. The exposure to the sea is not similar to all the coastal talukas of North Kanara. Karwar has maximum length of coastline followed by Honavar, Kumta, Bhatkal and Ankola. The area under different coastal regulation zone in different talukas varies as well (Table 15.1).

Karwar is highly urbanized taluk, with district head quarter. Therefore, there is huge population pressure, the famous Rabindranath Tagore Beach, Devbagh Beach Resort, Sea Bird Project, Warship Museum, owing to inflow of tourism, migrants as well as natural growth of population. The increasing population has posed significant pressure over the coastal zone. Land use in the coastal area is changing at speedy pace, which has resulted into high degree of conversion of traditional land use into commercial uses (Gururaja, Sameer and Ramachandra 2003).

Ankola taluk three villages located over the coast, few sandy beaches of Arabian Sea and Saydrian plateau on east, the major beaches are Baskal gudda, Nadibag, Shedikuli, Keni, Belekeri etc. The hinterland is more backward than the coastal region. Kumta taluk has an average elevation of 3 m. Maximum population pressures over the mouth of river Aghanashini and rest areas are less developed,

Table 15.1 Classification of coastal stretches in North Kanara in kms

Taluka	CRZ-I	CRZ-II	CRZ-III	Rivers	Total
Karwar	1.5	1.0	12	4.5	13.1
Ankola	7.1	0.6	8	2.5	16.2
Kumta	8.9	1.4	14	2.34	19.6
Honavar	–	4.9	6	4.35	17.2
Bhatkal	5	0.4	10	1.5	12.9
Total	22.5	8.4	51	15.1	79

Source: District planning board Karwar, North Kanara, 2006 and Directorate of Planning, 2010

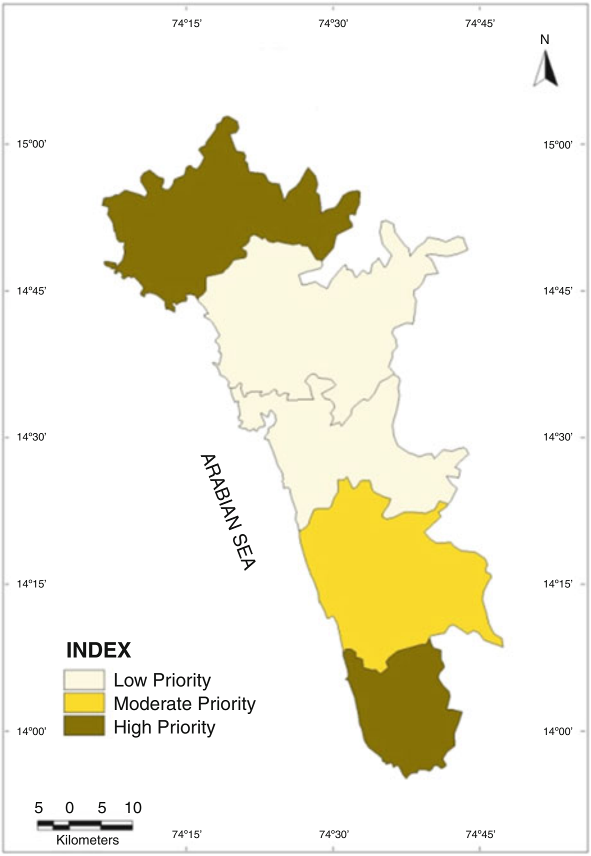


Fig. 15.5 Priority areas for ICZM

except Gokarna beach, Om beach etc., remaining coastal area is potential for development but not yet developed.

Bhatkal is also a coastal taluk, with heavy population pressure, sea shore along with lighthouse. The areas of different talukas and coastal villages have different sources kinds of resources, various kinds of environmental concerns and level of infrastructural development. Therefore a management strategy is needed which takes consideration of the above mentioned aspects, tin terms of their spatial variation. Thus on the basis of critical index, high priority areas for management have been identified (Fig. 15.5). The areas of higher criticality have been taken as the high priority zone and so on.

Thus, the uneven spatial development along the coastal development has resulted variation in the potentiality and challenges for development. Spatial integration considered while making management plans. For example, few talukas are facing immense environmental threat and natural hazards. Therefore they should be given priority in management planning. Initially there is a need for shifting the pressure from highly pressurised zones like Karwar and Bhatkal,

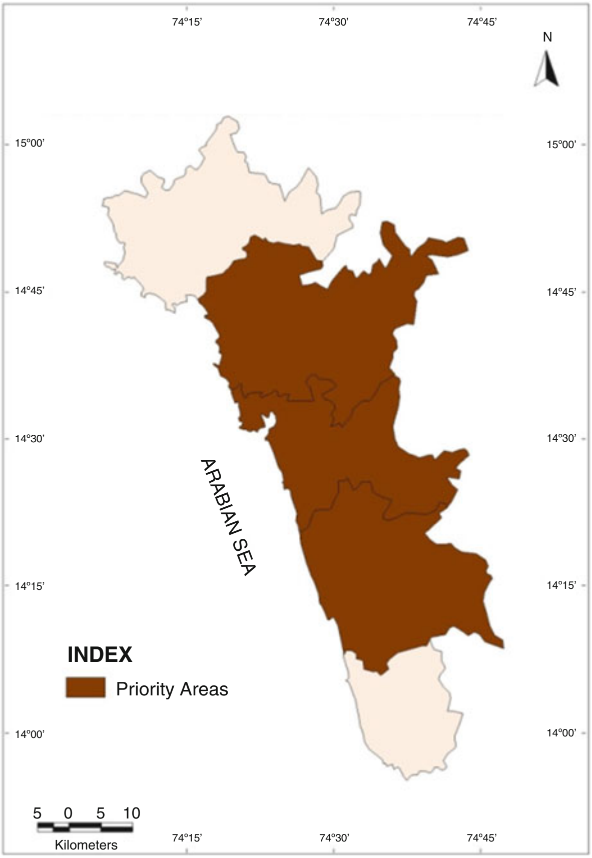


Fig. 15.6 Priority areas for tourism development

towards Ankola, Kumta and Hanavar, where resources not been developed up to its potentials. There is a need to check urban growth from the cities like Karwar and Bhatkal. The tourism developed in talukas of Ankola, Kumta, and Honavar should be promoted with special incentives (Fig. 15.6). New industrial area should be targeted towards areas of Hanavar, Kumta and Ankola, so that pressure from Karwar and Bhatkal can be released. Fishing activity should be promoted in these less developed areas. The talukas of Karwar, and Bhatkal are facing the intense challenge of land conversion. Thus, these areas require immediate land use planning (Fig. 15.7) and strict implementation of CRZ regulations.

15.4.4 North Kanara Coastal Zone Mapping Plan

North Kanara Taluks under coastal zone mapping are Karwar, Ankola, Kumta, Honavar and Batkal. Coastal land is well developed with a high degree of economic development followed by a high density of population, fisheries from sea and

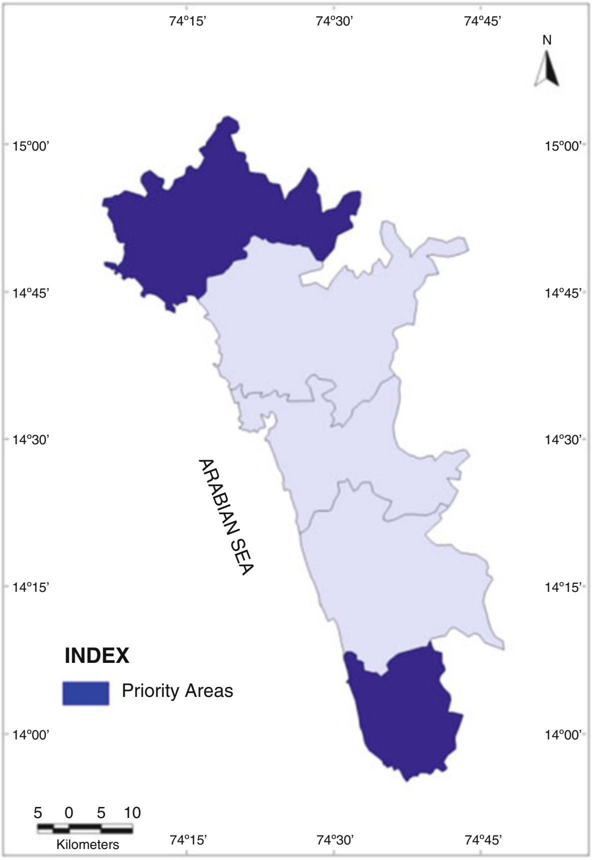


Fig. 15.7 Priority areas for land use planning

inland, molluscs, oysters and prawns. Coastal plain 16–48 km stretch wide, depending on the nature of estuaries and the inter-mediate tableland. Karwar port is situated on the Kali estuary. Laterite soil occurs extensively, low hills and plateaus. South of Aghanashini basin, the coastline is straight, sandy with dunes. Areas cleared of sand support a poor rice economy. Dumps of cleared sand dune landscapes, and locally these are known as Chitte lands.

The coastal stretches are classified into four zones as per notification with respective survey numbers and are given in a tabular form. The existing situation under each survey number, village wise along the coastal stretches is tabulated based on their occupational setting. Toposheet of 1:25,000 scales is used as the base map to depict the coastal features, HTL, LTL and different CRZ Zones. Mangroves, mudflats, saline areas, fish breeding centers and protruding cliffs along the beaches are classified as CRZ-I. Mangroves in each estuary are rated as good, moderate, very poor, though this categorization is not stipulated in the Notification. All the urban areas and planned cities (Municipal Areas and Corporation Areas) are

Table 15.2 Details of the CRZ of Karnataka and North Kanara (sq. km)

Types of CRZ	Karnataka (sq. km)	North Kanara (sq. km)
Total area between HTL and LTL	30.07	11.5
Total area under CRZ-III	172.71	51
Total area under CRZ-II	15.70	8.4
Total area under CRZ-I	54.96	22.5
Total area under CRZ-IV	0.60	0.15
Total area under CRZ	274.04	93.55

Source: Nandakumar and Muralikrishna, 2008

classified as CRZ-II, rest of the areas as CRZ-III. Mining and erosional spots, heritage and archeological areas coming under the CRZ are indicated.

In the Karwar beach there are a few small islands, namely Kangi, Kumargadgudda, Shimirgudda and Anjudip islands that are under the Sea Bird area project, which should be categorised under the Island category, CRZ-IV (Table 15.2).

15.4.5 Sectoral Aspects of ICZM

The coastal zones are suffering from various types of problems. Therefore, the different sectors should be taken proper consideration while management, but the management practices for the different sectors should not be conflicting. Some of the important strategies are as follows:

15.4.5.1 Land Resources

In order to protect the intrinsic scenic beauty of tourism potential and fragile coastal ecosystem all kinds of construction activities should be regulated as per CRZ notification guidelines. The development of the human settlement in the estuaries regulated. Strict measures are needed to preserve mangrove vegetation in the estuarine areas. Since a beach is the best protection for the coast, technological interventions like appropriately designed artificial reefs, submerged breakwaters, beach nourishment, strand vegetation etc., which can regenerate the beach should be preferred over construction of sea walls. Along the beaches, naturally formed pathway should be allowed instead of constructing roads. It will reduce the pressure at specific point and keeps the beaches free from over exploitation at only certain places.

In the coastal zone sand dunes are very sensitive and therefore vulnerable to the erosion. To protect this natural ecosystem the unauthorized construction should be stopped. Sand dunes should be stabilized through plantation of trees and sand binding grasses. This will enhance the protection of beaches from erosion along with enhancing scenic beauty. Preservation of dunes in the intermediate stage will be a better option to conserve the sand dunes. The demarcation of setback lines for beach resorts should be developed. Coastal shelter belts are needed to control the movement of sand dunes or sand dunes to protect the inland areas. It should be made compulsory or mandatory to all the land owners in the CRZ to grow local sand dune plants in open spaces, between the 200 and 500 m of the HTL. These plant cover may act as dense net and hence, minimize the movement of the sand. The plantation of trees like coconut casuarina etc. may function as wind barriers.

Further there should be proper waste disposable facilities like proper constructed toilets and waste bins with regular cleaning to preserve the sand dunes ecosystem. On the virgin beaches, government should acquire the lands and develop dune parks with proper fencing. Sand extraction, shells and singles in the coastal belts, should be controlled strictly to avoid the problem of disappearing sand dunes. In Karwar, no further construction to be allowed in order to preserve the sand dune ecosystem as they are already highly pressurized by tourism. Here plantation of sand dunes should be practiced in the open spaces. In talukas of Honavar, Kumta and Ankola government can work for the protection of the sand dunes. The strict enforcement of legal provision of CRZ notification and due punishment in case of not following the rule, Awareness about the coastal sand dunes ecosystem should be brought among local population, politicians and bureaucrats.

For checking the erosion of beaches, haphazard practices of sand dunes, leveling the sand dunes, destruction of mangroves and sand dune vegetation should be checked. Illegal sand mining should be checked by strict implementing of punishment of defaulters. Further *Gajani or Khar land* ecosystem should be preserved. Awareness about long term economic value of *Gajani* land should be spread among the local people. The long term environment and consequently economic benefit should be compared with the short term economic benefits. There should be regulation regarding the conversation of *Gajani* lands into concrete lands.

As far as the management of estuary is concerned, restricting reclamation for essential activities should be checked. Prohibition of disposal of unthread waste should also be checked to conserve this natural ecosystem. Sufficient fresh water discharge and sufficient tidal exchange to maintain estuarine characteristics should be ensured. The waste treatment level based on the assimilative capacity of particular estuarine system and away from critical habitats should also be determined. Location of chemical plants with toxic discharge near estuary should be avoided. The present practice for solid waste management in various local bodies are mostly using landfill method, which may not be viable in the long run due to limited land resources. Therefore, alternate technology, which has recovery component and makes use of limited land area and quick disposal methods should be adopted.

15.4.5.2 Water Resources

As far as the challenge of water pollution is concerned, numbers of efforts needed to tackle them. Solid waste should not be dumped and discharged. Treated effluents should be rechecked regularly. Existing catchment area conservation measures for west flowing rivers are not adequate. Extraction of water from these rivers is on the rise and the silt load is also increasing. Consequently, there is a reduction in flushing in these rivers leading to increase in the pollution load. Therefore, watershed management programmes in these river basins should be implemented on priority. Similarly the number of dams that these river systems can sustain can be studied and optimized. The mangrove afforestation as done in Kumta and other regions should be extended to other potential estuarine areas as well. There should be limited use of low lying fields for paddy cultivation and aquaculture since they may cause saline water intrusion in groundwater aquifers.

Water front development is an important policy to preserve the water resources. Settlements are heavily inhabitated along the water front. Therefore no new settlement should be allowed along the water front outside the present existing settlement areas. Secondly the future development of the settlements along the waterfront should be allowed only in the landward direction. Recreational areas should be developed along the water front in urban areas. Though all the major industries are separately monitoring their emission load, effluent quality and wastewater discharge quantity, a composite picture of the pollution load of major industrial belts and the surrounding areas are not known. The outflow from sewage treatment facilities of the local bodies and the aquaculture farms to the nearby estuaries has high organic pollution potential and is not monitored regularly (World Health Organisation 1985). Construction of breakwater/seawalls should be subjected to comprehensive environment impact assessment.

15.4.5.3 Tourism

The boom of tourism in North Kanara has resulted into massive developmental activities on the coast. Therefore, the beaches are under serious threat due to increasing number of resorts and hotels located on the sea shore preference should be given to accommodate the tourist in the settlement as the playing guest rather than developing new resorts and hotels. It will release pressure from the coastal ecosystem. Policy encouragement should be given in this regard. Secondly the taluka of Karwar and few areas of the Honavar are heavily pressured by the tourism activity. Therefore, there is a need to encourage and open up new areas in the less develop areas interims of tourists like Ankola and Kumta. The area for new potential tourism development should be identified in the areas pressure is very less. The areas Belekeri and Manjaguni in Ankola and Bailur, Shiralli and Gorate in Bhatkal are having beautiful beaches which have not been explored up to its potential. Further, tourism activity in North Kanara is seasonal in nature, which have not have been explored up to its potential.

Further tourism activity in North Kanara is seasonal in nature, which is vulnerable to various forces. An optimum size of desirable tourist traffic for the better development of the socio-economic development should be identified. The holding capacity in terms of tourist potential in different tourist destinations should be determined and policy should be made in accordance with it. The tourism facility should be developed by developing infrastructure, so that the number of tourists should be increased in areas, where achievements are far behind the potential capacity. Location of new beaches should be determined with consideration of beach resource, ecology and environmental impact assessment. For managing tourism sector, management should be done in a way that potentialities and concerns at micro-levels should be taken into consideration.

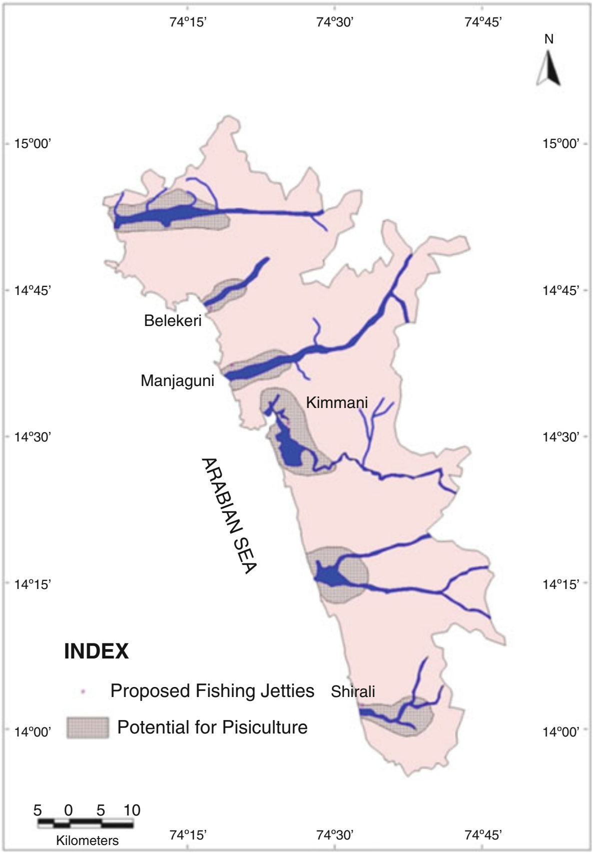
15.4.5.4 Fishery

The fish production is very unstable in North Kanara. Loss of fish diversity, overexploitation and livelihood security of small and marginal fishermen are another cause of concern. Therefore a sustainable strategy is needed in this sector. The main focus should be given in deep fishing with high yielding technology. Secondly, the brackish water and inland fishing should also be given encouragement. The numbers of trawlers should be controlled because the increasing the numbers of trawlers reason for the pressure over the seas of North Kanara. The technological improvement is needed, so that unmatured and small fishes could not be caught. It will ensure the sustainable availability of resources. Small and unorganized fishermen should be given subsides and incentives to sustain their livelihood security. They should provide net against uneven competition from the corporate sectors. Development of cold storage, road linkages and transportation, facilities of workshops for repairing their boats and processing and packaging facilities etc. should also be given proper consideration. Fishing jetties are very important to harness the resources of deep sea. These fishing jetties should be located in suitable places such as Belekeri, Manjaguni, Kimmani, and Shirali (Fig. 15.8).

These areas have high potential but exploitation is low. Fishing jetties like fish processing, oil extraction plants, fish meal plants, drying or fishes should not be proposed in order to provide environmental problems. These activities should only be permitted at specified places with permissible environmental norms. These jetties have been proposed in the relatively less developed talukas in terms of fishery development of Ankola, Kumta and Bhatkal.

Pressure on benthic organisms and their survival as these are thrown overboard and are discarded dead. The all weather and overnight fishing off Bhatkal has accelerated the decline in catfish, endemic to the North West Coast of Karnataka. In the seas around India, 22 catalogued species of marine mammals occur. They visit the coastal waters for feeding or breeding. There are also reports of marine turtle nesting in Devagad Guda islands off Karwar. Turtles and dolphins get entangled in fishing nets such as gill nets, trawl nets and purse seines occasionally

Fig. 15.8 Potential areas for fishery development



off Karnataka coast. These are included and protected under Schedule I of the Indian Wildlife (Protection Act) 1972 and their fishery is not permitted. A study should be executed by the Department of Fisheries in collaboration with Fisheries Survey of India and Central Marine Fisheries Research Institute to develop database covering fishery and non-fishery factors to evaluate and monitor the biodiversity stock positions, fluctuations etc. in the near and offshore waters. Aquaculture Authority and Karnataka State Pollution Control Board should carry out monitoring of industrial areas on a cluster basis especially in the dry season.

15.4.5.5 Infrastructure

The unplanned Infrastructure development along the coastal zone is major concern in North Kanara, which is leading to a variety of ecological problems. The distribution of these factors is also not similar all along the coast. This process of infrastructure development is causing environmental disorder in the areas, were it

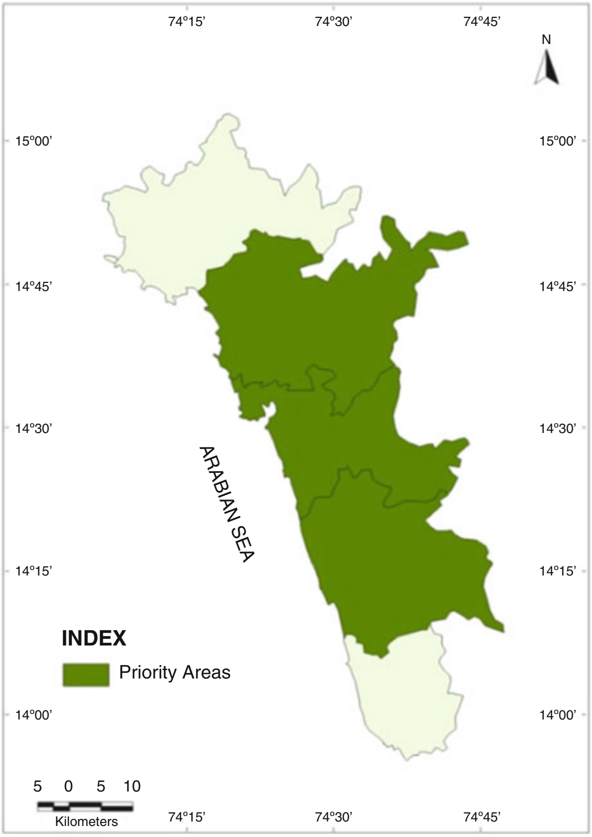


Fig. 15.9 Priority areas for infrastructure development

has not been developed in accordance with the CRZ notification, while on the other hand lack of infrastructural development in some areas are hindering the process off development. Therefore, infrastructural development should be taken under the priority in ICZM. The market centers should be linked with the settlement. Facilities of cold storage and ice plants should be developed to develop the fisheries activities. The road network should be developed in taluks, which are less developed in terms of roads per square kilometers. This lack of road density has hindered the growth of tourist and other economic activities. Encroachment of natural ecosystem should be strictly avoided (Fig. 15.9).

15.4.5.6 Livelihood Security

Uplifting the standard of living of the society is the ultimate cause of any management strategy. Livelihood security is very important for this. Since the tourism is a prime mover of the economy of the North Kanara and it is seasonal in nature, therefore, livelihood is the major cause of concern of huge section of the society.

Secondly, fishing is also banned during the monsoon season. Thus, there is a great challenge for providing livelihood security throughout the year. For livelihood security alternative opportunities should be developed. For example, in the North Kanara there is a great potential of sea grass and seaweeds based industries. So, there should be a focus in this direction. Secondly, there is possibility of developing local crops, which may be beneficial for people involved in the unorganized services further tourism.

15.5 Priority Areas for Management

In Karnataka, particularly in North Kanara, the coastal zone is experiencing immense pressure over its resources. North Kanara is very fortune in terms of availability as well as the endowment of their resources (both natural and human), but increasing pressure of natural and anthropogenic factors especially tourism is leading towards ecological imbalances, environmental degradation and their other impacts which are affecting the livelihood security of a large section of society, which are directly or indirectly dependent on the coastal zone. The distribution of resources, level of resource endowment, resource utilization pattern, pressure of population and consequent environmental concerns are not evenly distributed. The nature and intensity of issues and problems are variable over time and space. Therefore an integrated coastal zone management is needed for the coastal zone of North Kanara. However a number of problems have been emerged in arena of coastal zone of North Kanara, but the priority areas, which should be taken under consideration for the coastal zone management of North Kanara, are pollution control as the high pollution level is leading to emergence of a number of other problems and ultimately damaging the environmental health of coastal zone (Fig. 15.10).

Development of Fisheries is another issue, which should be given emphasis in management because it is one of the most important sources of livelihood of the majority of local people. Secondly there are number of issues related with fisheries such as biodiversity, livelihood and food security, pollution. Coastal erosion and mangroves should also give proper emphasis according to the requirement of people in the coastal zone of North Kanara.

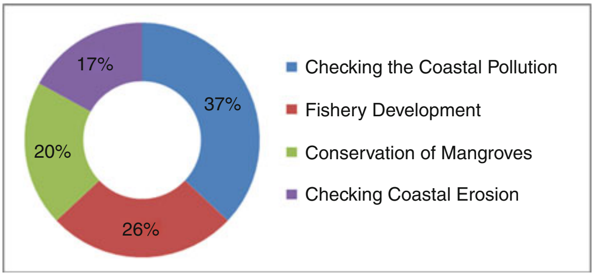


Fig. 15.10 Priority areas for management in coastal zone in North Kanara coast (Source: Primary survey, 2011)

15.6 Conclusion

However, the coastal zone of North Kanara presents various kinds of problems and their solution is different as well. However, these solutions may achieve if an integrated approach will be adopted. The pressure zone should be relieved form the immense pleasure for diffusing the pressure underused areas should be utilized more intensively. In the same way sectoral management also needed. The various interrelated sectors, such as tourists, infrastructures development, sanitation, implementation of CRZ etc. should be dealt through a comprehensive policy. Institutional integration also essential, various government, private and individual organization should work together to implement the programmes in an effective way.

The entire process has been vitiated in Karnataka, as the CZMP maps are inadequate, and do not include areas which are CRZ, as per the definitions given in the notification. This is a serious lacuna and must be remedied. There is a clear need for proper mapping of the coastal area, and proper classification into various CRZ zones. Stricter implementation of laws, when giving clearances for projects, is required. Usually required procedures, such as EIA and Public Hearing are not followed. Land acquisition is without need to the due procedures. Laws are by passed, by the Government, and private industry. This reflects the priorities of the State as being development, and not protection of environment, or local peoples. Even while new development and thereby changes, are taking place on a very large scale along the coastal region, what is not being taken into consideration is the need to understand these changes with a larger and long term perspective. The government and its other arms like Pollution Control Board are satisfied at looking at these developments in the conventional style, the developments, both in volume and complexity, beyond the way it is understood today.

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Part III
Other South Asian Countries

Chapter 16
Anthropogenic and Environmental Disturbance Factors in the Annapurna Conservation Area of Nepal

N.G. Pricope, J.D. All, and L. Miles

Abstract Human-environment interactions in the Nepali Himalaya are a topic of increased interest given the importance of the region from a biophysical, hydro-climatic, and socio-economic point of view. In this paper, we discuss a range of anthropogenic and environmental disturbance factors affecting one of the best-known conservation areas in Nepal: the Annapurna region. Similar to other mountainous environments, this region has been experiencing heightened human and natural pressures resulting in environmental degradation from a variety of multiple causal factors, such as deforestation, over-grazing, improper cultivation techniques on poor soils and slopes and haphazard policy and management decisions regarding conservation and tourism. Mountain ranges are very sensitive to environmental changes and even slight alterations and imbalances can result in exponentially detrimental effects not only for the livelihoods of local and regional communities, but also biodiversity and ecosystem functioning. We utilize a combination of field-collected data such as ground control points and remotely-sensed imagery and datasets and, acknowledging the variability of the constantly changing landscape, we provide a preliminary quantitative analysis of environmental and socio-economic impacts in the Annapurna Conservation Area to highlight the extent of anthropogenically-induced changes in the region over the last decades.

Keywords Anthropogenic disturbances • Climate change and variability • Conservation areas • Nepal • Himalaya region

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16.1 Introduction

The Himalayan mountain range is one of the major mountain ranges of the world. This range stretches across Nepal, Bhutan, northern Afghanistan, northern India, northern Pakistan and the Tibetan Plateau of China. It is the highest and most massive on earth and contains over 100 mountains which exceed 7200 m in height and several over 8000 m in height (Yang and Zheng 2004) including the tallest mountain in the world, Mount Everest. The mountain system runs east-to-west and covers a length of roughly 2400 km and an area of roughly seven million square kilometers (Snedden 2006; Singh et al. 2008; Xu et al. 2009). The Himalayas are home to more than 100 million people, some of whom live at altitudes above 5000 m (Shrestha 2005). This remote area and livelihood attracts people from all over the world, from tourists to alpinists, to come and interact with the mountain cultures. Therefore, the tourism industry is a large and lucrative business and for a country like Nepal and is referred to as "the natural infrastructure" of the country (MacLellan et al. 2000, 173). However, this infrastructure is reliant on a mountain range that is still tectonically unstable, ecologically and environmentally fragile; in a country that is economically and politically underdeveloped and very densely populated (Byers 2005; Cui and Graf 2009; Marston 2008; Tiwari 2008) (Fig. 16.1).

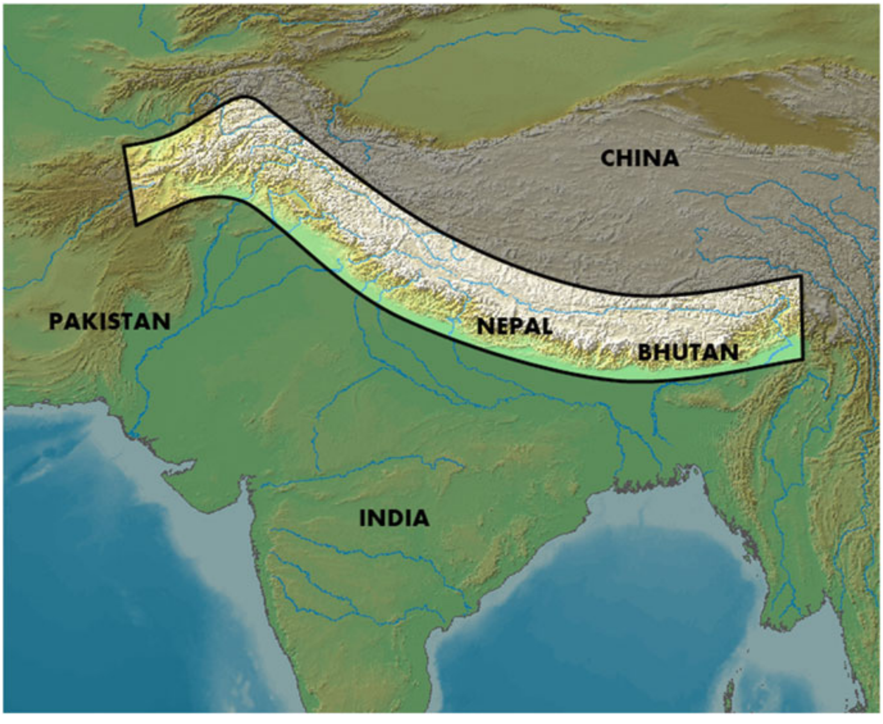


Fig. 16.1 Inset of Himalayan mountain range

Like most mountain areas, the Himalayas are experiencing the dramatic effects of environmental degradation from a variety of multiple causal factors. These factors are being driven by deforestation, over-grazing, improper cultivation techniques on poor soils and slopes and mismanaged administrative decisions regarding conservation and tourism. Mountain ranges are very sensitive to environmental changes and any slight change can be an exponential detriment to not only the livelihoods of those that live there, but the flora and fauna as well. These changes can make mountain ecosystems more susceptible to fire, soil erosion, landslides, avalanches and loss of both habitat and biodiversity (Becker et al. 2007; Beniston 2003; Byers 2009; Lambin and Geist 2006; Snedden 2006). For example, some species of plants can grow in certain elevations and settlements cannot be established in places with higher slopes. Moreover, certain flora can grow better in certain slopes and aspects (Sesnie et al. 2008). Though the local peoples that live in these areas are earning money from the increased tourism, the mismanagement of the land to accommodate the increased tourism is damaging the local environment in terms of forest thinning and degradation due to the construction and modernization of the roads and trails in these areas. This ultimately leads to the depletion of natural resources in this ecosystem and it's the locals who have to bear witness to the degradation as well as endure any/all adverse effects from it (Gulia 2007). The local people, known as Sherpas, having lived in the area for hundreds of year, understand well that their natural treasures are being lost as the environment is damaged. The Sherpas, who live primarily in the upper mountain regions of the Himalayas, make their living as farmers, traders, mountain guides and climbers, (Snedden 2006) so their ways of life are directly affected by environmental climate change. Another important aspect of climate change is its far-reaching consequences. Since this is a global issue as well as a regional and local issue, areas that are protected with the infrastructure to mitigate these effects still suffer.

Observing and documenting of these environmental changes can be quite difficult and there are several challenges involved. One of the reasons behind the difficulty for the study of environmental aspects mainly in developing countries was the lack of suitable topographic data (Goncalves and Fernandes 2005; Liu et al. 2004; Ustun et al. 2006). Another issue is the scale and size of the area of interest. For larger areas of interest, a thorough analysis based on data collected directly was historically nearly impossible. However, after the development of new remote sensing technologies, automatic Digital Elevation Models (DEMs) which are digital representations of surface topography can easily be generated and analyzed by computers (Tulu 2005). These DEMs can then be coupled with ground data to give a better understanding as to what the ground data has observed. In Nepal, where people live and work in high elevations, it is incredibly important to quantify these values and provide these results to the people so that they may have a clear interpretation of the land. From this interpretation, these results can be effectively used to determine appropriate land use/land cover of the area in terms of growing crop, maintaining biodiversity, and hazard assessment.

This study aims to identify the causal factors behind biodegradation and environmental changes in a Himalayan-protected area of Nepal, specifically, the

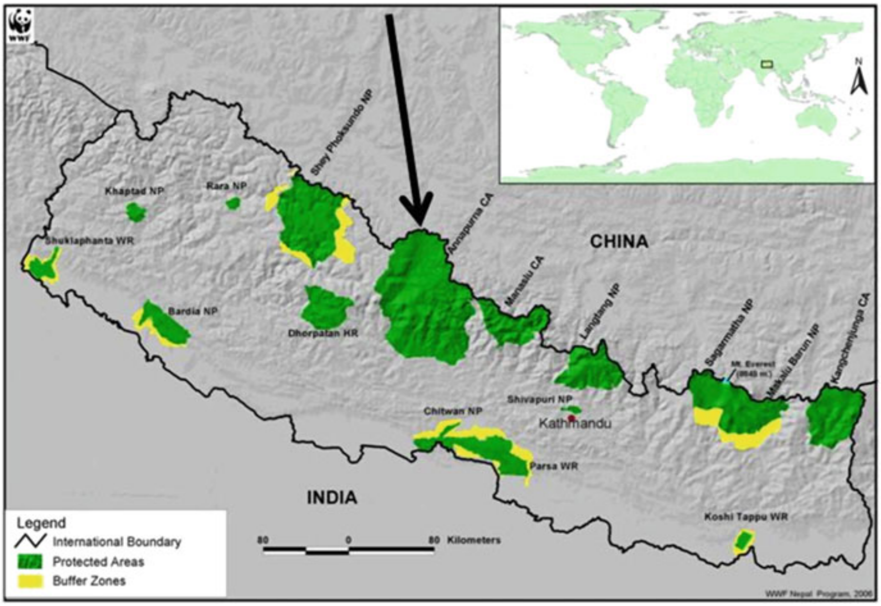


Fig. 16.2 Protected areas of Nepal – Annapurna conservation area (*arrowed*) (WWF)

Annapurna Conservation Area. Established in 1992, the Annapurna Conservation Area is Nepal's first conservation area and the largest protected area. Located in north-central Nepal, bordering the Tibetan Plateau of China, it covers an area of 7629 km^2. It was originally established in 1985 and gazetted in 1992. The altitudinal range of the Annapurna Conservation Area is 790 m from the lowlands in the south, to the peak of Annapurna I at 8091 m (Bhuju 2007). This area is rich in both topography and biodiversity with tall mountains, deep valleys and is home to over "1226 species of flowering plants, 102 mammals, 474 birds, 39 reptiles and 22 amphibians. (NTNC.org)" (Fig. 16.2).

This study can provide possible causal factors such as human-environment interaction and the subsequent effects in terms of management practices and tourism initiatives. From what has been established, the assumption is that the majority of the effects have been negative. These effects include biodiversity and habitat loss, glacial melting, deforestation and erosion. A working hypothesis for this research project is that the causal factors for these losses are by anthropogenic means in recent years. By utilizing data gathered in the field such as ground control points and acknowledging the variability of the constantly changing landscape, it will provide a basis of understanding for the environmental and socio-economic impacts in the Annapurna Conservation Area.

Tourism is a driving force in the Himalayan Mountain range. With so many of the tallest and dangerous mountains to climb in the world, as well as the unique mountain ecosystem that encompasses the area, it makes for a very attractive recreational and research opportunity. However, the increased amounts of tourist activity coupled with the effects of climate change are making these environmentally fragile areas even more fragile. This problem stems from poorly managed adventure tourism, where development is overriding conservation which leads to further mountain ecosystem degradation (Baral et al 2007; Byers 2009). Baral et al. (2007) also adds the important issue of how the locals respond to economic incentives for practicing conservational approaches. The Annapurna Conservation Area is home to over one hundred thousand people (NTNC.org, WWF), all who lived and worked there before the land was designated as a protected area and thus will not respond favorably to changes in their livelihood. The combination of economic underdevelopment, poverty, land access and environmental degradation have made influencing target populations with conservation initiatives and best management practices very difficult and time intensive.

16.2 Data and Methods

Data for this research was gathered from multiple sources. The major source of the data is the Ground Control Points (GCPs) collected in the Annapurna Conservation Area during a field visit in 2010. A material data sheet was prepared for the visit in this area and was used to collect as much information on the local landscape of the area using as many variables as possible. The instruments used to acquire these GCPs were a GPS (Global Positioning System) for measuring latitude, longitude and other spatial values. An inclinometer and engineering compass was used for slope and a standard compass for aspect. The GCP's were collected randomly under a certain linear distance in flat areas as well as rugged terrain. Additionally, opportunistic points were taken whenever a significant change in elevation, slope, aspect or distinct land feature was encountered such as ridges, valleys, forests, bare land, grasslands and developed settlements to provide a more robust dataset. The variables used in this project will be the disturbance factors based on each point taken during the trek through the protected area. Each disturbance factor was ranked based on the level of disturbance at each point: no disturbance as 0, ~20 % disturbance at 1, ~40 % disturbance as 2, ~60 % disturbance as 3, ~80 % disturbance as 4, and completely disturbed (100 %) as 5. The slope degree values had to be standardized to this same rubric in order to be applicable as a factor for disturbance. It was standardized as angles from 0° as 0, 1–18° as 1, 19–36° as 2, 37–54° as 3, 55–72° as 4 and 73–90° as 5 as seen in Appendix 1.

ASTER DEMs were obtained from the NASA Global Digital Elevation Model (GDEM) website (http://www.gdem.aster.ersdac.or.jp/). The GIS shapefiles were obtained from the Western Kentucky University Center for GIS. Once all of the data from both the instruments and the remote sensed data were obtained, further refinement of the data set was necessary. This was accomplished using ArcGIS™. The ASTER raster data is originally divided into individual files and must be mosaicked together into one continuous image. Once the image is mosaicked it is then projected into the Universal Transverse Mercator (UTM) coordinate system in

Zone 44 North which is located across the country of Nepal. Subsequently, the mosaicked image must then be clipped to the borders of the Annapurna Conservation Area so that the analysis could be accomplished accurately within the appropriate area of interest.

Once the disturbance factors have been documented, the next step is to appropriately digitize and visualize the dataset. All nine of the disturbance factors: slope, fire, grazing, wood harvesting, limb cutting, digging, fauna, erosion and dead trees were compiled in a Microsoft® Excel spreadsheet. The dataset was then imported into IBM SPSS Statistics 19 to perform a hierarchical and k-means clustering analysis to identify disturbance hotspots. Clustering designates groups of data values that are homogenous to each other and heterogeneous to others. This method is preferred to distinguish similar and different areas based on the level of disturbance. Each clustering methods have strengths and drawbacks so both were utilized for this research project to see which better represented the dataset and provided more concrete results. Hierarchical (Agglomerative) clustering begins with all elements individually and then takes steps to combine the clusters until there is only one large cluster. Alternatively, k-means clustering aims to partition data into mutually exclusive clusters based on certain characteristics (e.g. nearest mean). Each clustering methods works to help with data reduction into manageable pieces. Hierarchical clustering is normally suitable for smaller data sets due to its clearer visualization of cluster memberships. As the dataset increases, those cluster memberships become harder to find and designate. To counteract this, the k-means clustering is done. K-means clustering is more suitable for larger datasets because it partitions the data into clusters rather than merely show the hierarchical structure of the variables. For the hierarchical clustering, the cluster methods used furthest neighbor with squared Euclidean distance intervals. This would then save a single solution with three total clusters. The k-means clustering utilized a "classify only" method which saves the cluster membership with three total clusters. When the analysis was complete, the hierarchical clustering added an addition column to the dataset, "clus3_1" and the k-means clustering added a column, "QCL_1". These columns assigned a number between one and three based on disturbance similarities. These columns were then imported into ArcMap®. The GCPs are then projected into Universal Transverse Mercator (UTM) Zone 44 North so it can properly overlay onto the raster DEMs. The next issue is finding the correct raster values the GCPs. This was done in ArcMap® using the Extract Values to Points tool and was run for the GCP layer for the Annapurna Conservation Area. This tool adds a new field to the GCP attribute table and is populated with a raster value where each point is located. The GCPs are then joined to the Annapurna shapefile and overlaid onto the DEM so that the spatial locations of the clusters relative to the area of interest could be determined. This is observed in Appendix 2.

Additionally, a principle component analysis (PCA) was performed to analyze the contribution of the major variables that account for the most disturbances in the study area. Instead of utilizing all nine variables, PCA is able to illuminate the more influential factors. It creates a component score coefficient matrix based on each factor of disturbances to assist in understanding the interrelationships between each variable and thus make an assumption for what the component is representing.

16.3 Analysis and Discussion

16.3.1 Hierarchical (Agglomerative) Clustering

The analysis produced a dendrogram as seen in Appendix 3. The dendrogram provides a visual representation of the groups that are clustered based on a relative distance scale between 0 and 25. Since the dataset is so large, it is very difficult to determine the cluster membership in the early clustering phases. Even though relative distance becomes more apparent as the graph moves from left to right, the cluster membership remains unclear. Since the dataset contains 166 points, it is too large for agglomerative clustering to handle and thus, k-means clustering was utilized.

16.3.2 K-Means Clustering

From what was designated in the analysis, the k-means clustering produced three clusters based on similarities and differences in disturbance levels as seen in Appendix 4. The spatial distribution of the three clusters is show in figure in the Appendix 4. Initially, it is somewhat difficult to determine which cluster represents which level of disturbance. However, using the attribute table to match the disturbance values for each factor and then seeing which cluster the values is associated with, I determined that cluster one (*red*) are areas of high disturbance, cluster two (*green*) are areas with medium disturbance, and cluster 3 (*blue*) are areas with low or no disturbance. Slope is the critical determinant of these clusters. It is assumed that the higher the slope, the more difficult a place is to reach and subsequently disturb. This assumption holds as areas in cluster three (Low/None disturbance) had typically higher slopes than those in cluster one (High disturbance). Also, the effects of grazing and erosion are closely related to the slope. Cattle prefer to graze on areas with relatively gentle slopes. Erosion will typically be more prevalent in steeper slopes. This leads to the PCA for further examination of how the variables are interrelated.

16.3.3 Principle Component Analysis (PCA)

The Principle Component Analysis produced several figures and tables for interpretation. The first table shows the contribution of each individual component for the total variance. As shown in Table 16.1 below, the first component accounts for nearly 50 % of the total variance and the first four to five components account for nearly 90 % of the total variance.

The next figure, known as the scree plot, again shows the decreased contribution of the nine components in a more linear representation. After the first four to five

Table 16.1 Total variance explained

Component		Initial Eigenvalues[a] Total	% of Variance	Cumulative %	Extraction Sums of Squared Loadings Total	% of Variance	Cumulative %
Raw	1	10.536	46.331	46.331	10.536	46.331	46.331
	2	3.687	16.212	62.543	3.687	16.212	62.543
	3	2.991	13.153	75.696	2.991	13.153	75.696
	4	2.111	9.281	84.977	2.111	9.281	84.977
	5	1.375	6.045	91.022	1.375	6.045	91.022
	6	1.067	4.690	95.713	1.067	4.690	95.713
	7	.450	1.978	97.691	.450	1.978	97.691
	8	.273	1.199	98.890	.273	1.199	98.890
	9	.252	1.110	100.000	.252	1.110	100.000

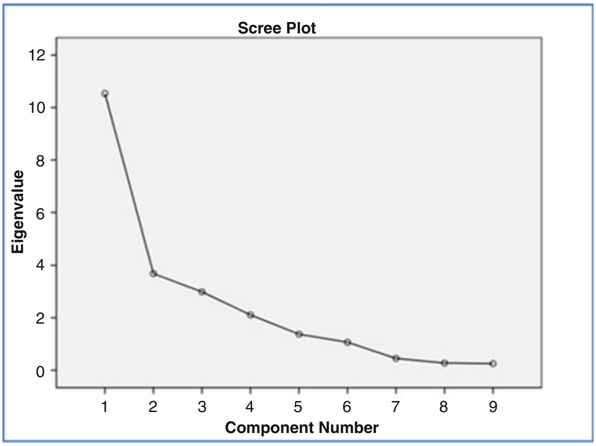


Fig. 16.3 Scree plot of total variance

component the rest of the components contribution becomes smaller and less significant (Fig. 16.3).

The component score coefficient matrix shown in Table 16.2, suggests the factors responsible for the corresponding components. The largest contributors have been circled with corresponding colors to match their contribution in each component with red signifying the largest contribution, blue for the second largest, and green for the third largest. Using slope as the determinant for these factors it can be expected that component one is a highly forested area with relatively flat slopes which allow for easier access for timber harvesting. Component two signifies open areas with relatively flat slopes which would allow for grazing and agricultural development. Component three signifies open areas with steeper slopes which do not allow easy access so the primary factor in this component is erosion and possible use of agriculture practices on the slopes such as terracing.

Table 16.2 Component score coefficient matrix

Component Score Coefficient Matrix[a]

	Component								
	1	2	3	4	5	6	7	8	9
Slope	.068	-.034	.320	.143	1.036	-.094	-.013	.057	.093
Fire	-.056	.156	.127	-.089	.053	1.102	.103	.135	-.105
Grazing	.079	.766	.010	-.614	.120	-.444	-.021	.041	.022
Wood	.419	-.172	-.097	-.268	-.104	.402	-.248	-1.414	2.591
Limbs	.436	-.214	-.049	-.272	-.105	.185	.321	1.402	-2.672
Digging	.127	.362	-.555	.814	.182	.184	-.092	.088	-.087
Fauna	.003	.008	.002	.024	-.009	-.033	.993	.004	.199
Erosion	.123	.211	.699	.522	-.634	-.137	-.119	-.096	.010
Dead Trees	.001	-.005	.001	.001	-.020	-.010	-.059	.875	.497

Extraction Method: Principal Component Analysis.
Component Scores.

a. Coefficients are standardized.

16.4 Conclusion

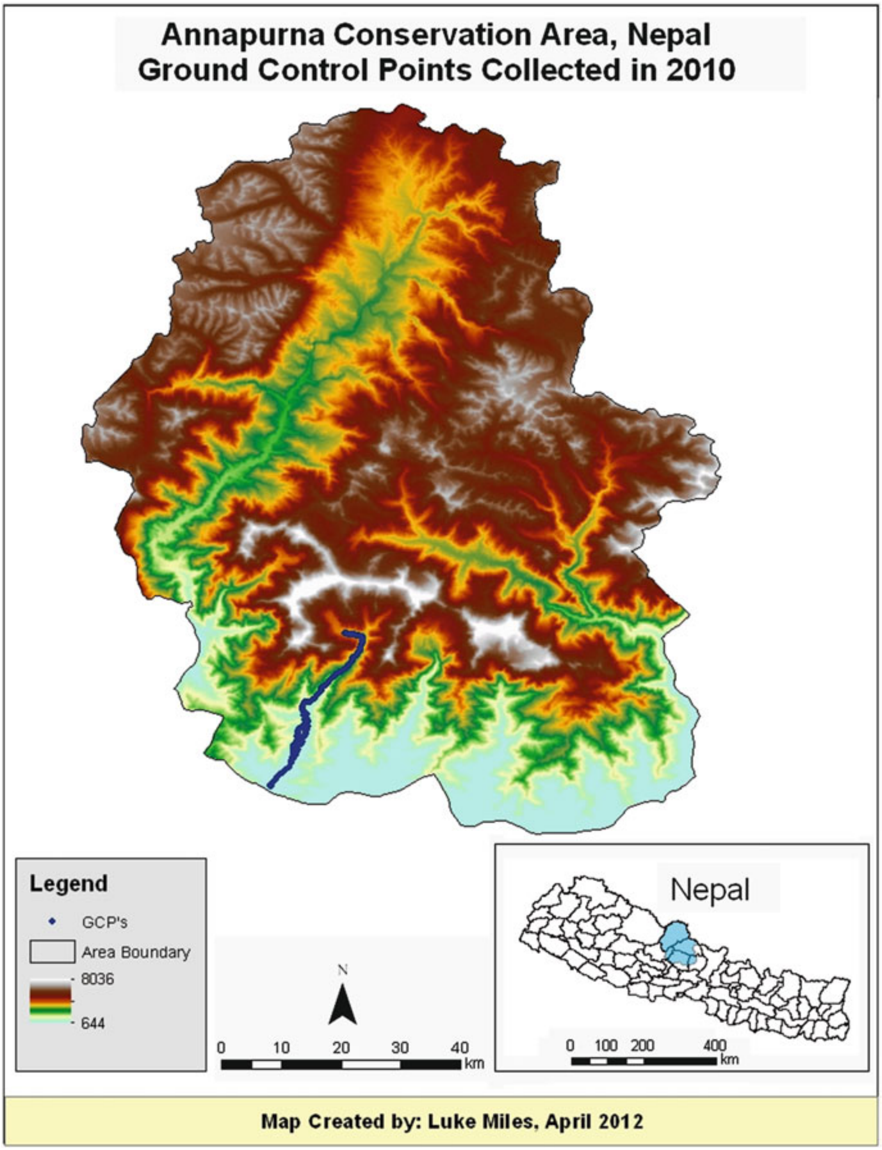
In the Annapurna Conservation Area, the major disturbance factors are slope, fire, grazing, wood harvesting, limb cutting, digging, fauna, erosion and dead trees. Although the hierarchical and k-means cluster analysis did not show any specific spatial trend, it did provide a basis for which to determine overall disturbance levels based on the three clusters. Utilizing slope as both a factor and an indicator, the clusters contributions are interpreted easier. The areas with the highest slopes have the least amount of disturbance, those with medium-level slopes have medium amount of disturbance and those with gentle or no slope present high levels of disturbance. This relationship is predicated on the fact that cattle cannot graze and humans cannot easily access these areas of higher slopes. The principle component analysis shows that the major contributors to disturbance levels among the nine variables are: slope, wood harvesting, limb cutting, erosion, and grazing. Similarly, slope is again a factor and an indicator. The first two components have very small contribution from slopes which signify that the areas are relatively flat and easy to access by both humans and animals and are indicated by the high contributions to timber harvesting and grazing. The last component has a higher contribution from slope so there is little contribution from timber harvesting or grazing due to the difficulty of accessing the land. Major causal factors behind these disturbances as climate change, overgrazing, poor management practices and increased (mismanaged) tourism. Continued efforts on educating the locals with appropriate incentives and initiatives as well as proper management strategies and practices would help to alleviate some of the current issues within this protected area.

Appendices

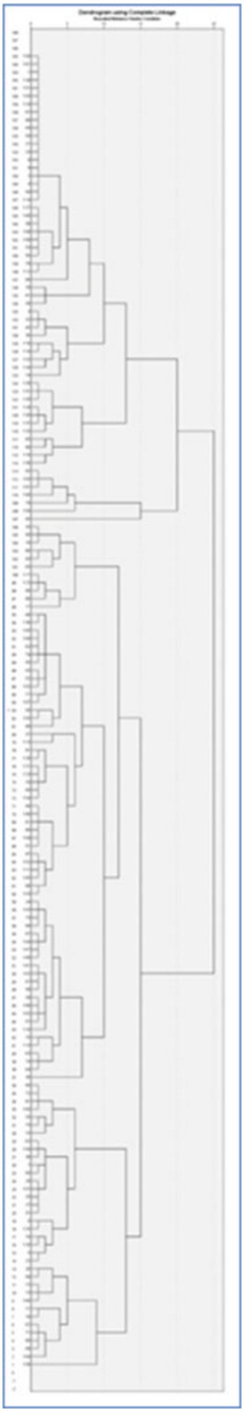
Appendix 1: Sample of GCPs Showing the Standardized Disturbance Factors (166 Total)

H	I	J	K	L	M	N	O	P	Q
Slope	Slope Deg	Fire	Grazing	Wood	Limbs	Digging	Fauna	Erosion	Dead Trees
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
1	15	0	3	0	0	3	0	0	0
0	0	0	0	0	0	0	0	0	0
3	45	0	3	5	5	5	0	0	0
0	0	0	4	5	5	3	0	0	0
2	30	0	3	5	5	2	0	3	0
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
1	20	0	4	5	5	2	0	2	0
1	7	0	0	5	5	4	0	4	0
1	5	0	0	5	5	2	0	1	0
1	5	0	0	5	5	2	0	2	1
1	5	0	4	0	3	0	0	0	0
1	5	0	4	5	5	4	0	3	2
1	10	0	0	2	5	2	0	2	0
0	0	0	0	5	5	0	0	4	0
0	0	0	0	5	5	4	0	4	2
4	70	0	0	0	0	0	0	6	0
1	5	0	0	5	5	4	0	0	0
0	0	0	0	0	0	0	0	0	0
1	10	0	3	5	5	5	0	0	0
0	0	0	0	0	0	0	0	0	0
4	70	0	3	3	5	0	0	3	0
2	30	0	3	5	5	3	0	1	0
2	20	0	3	4	5	2	0	2	0
1	5	0	3	5	5	2	0	1	0
2	25	0	0	0	0	3	0	0	0
3	45	0	2	0	0	3	0	2	0
2	25	0	5	0	0	3	0	2	0
2	20	0	2	5	5	2	0	2	0
2	20	0	3	0	0	3	0	1	0
2	20	0	5	5	5	5	0	5	0
1	10	0	2	5	5	0	0	3	0
2	20	0	0	2	5	3	0	3	0
2	50	0	2	2	5	0	5	2	0

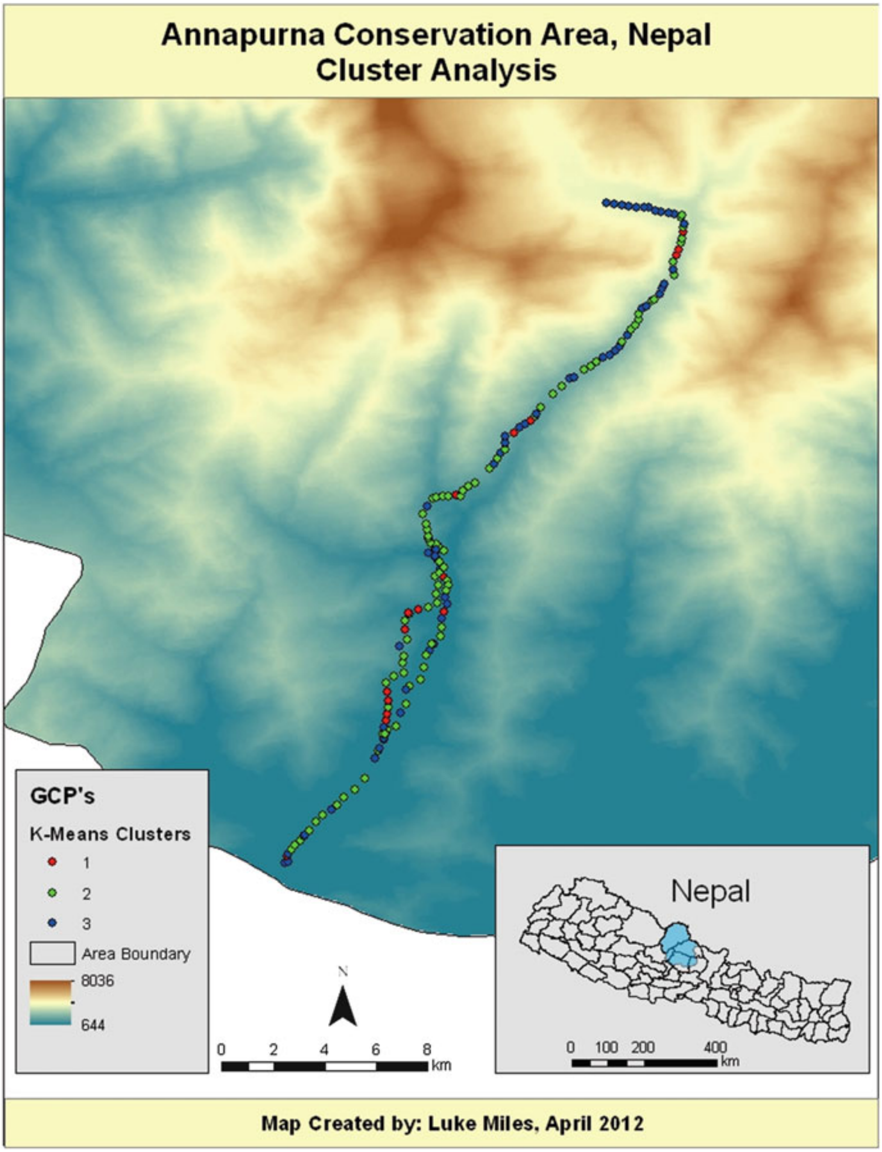
Appendix 2: Area of Interest (Annapurna Conservation Area)



Appendix 3: Dendrogram Created from the Hierarchical (Agglomerative) Clustering Analysis



Appendix 4: K-means Cluster Analysis



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Chapter 17
Mangrove Diversity Across Salinity Gradient in Negombo Estuary-Sri Lanka

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Abstract The study was conducted in the Negombo estuarine lagoon locates in the Gampaha District of Sri Lanka. In this research, an investigation was carried out to identify and assess the distribution pattern of mangrove diversity across salinity gradient in the lagoon. A field survey was performed to collect primary data and vegetation sampling was carried out in two transects along the periphery of the lagoon. Located sample size is 5 m × 10 m. Fifteen samples were selected maintaining distribution of species heterogeneity. Only mangrove species were enumerated. *In situ* field-testing of salinity was carried out at monthly intervals during October 2012 to September 2013 for 15 samples. Shannon-Wiener diversity index was calculated to compare about the diversity of mangrove species. The Inverse Distance Weighted (IDW) interpolation technique in ArcGIS was performed to prepare spatial distribution maps. There are 18 mangrove species identified belonging to 14 genera and 12 families. Among them 14 species are "True" and 4 species are "Mangrove Associates". *Rhizophora mucronata*, *Rhizophora apiculata*, *Avicennia officinalis*, *Excoecaria agallocha and Acrostichum aureum* are the most common species and *Aegiceras corniculata*, *Aegiceras corniculata*, *Bruguiera sexangula* and *Xylocarpus granatom* are the least common true mangrove species types found in the Negombo lagoon. Spatially the highest mangrove species diversity could be identified in the southern quarter and a small patch around the outlet of the lagoon. Relatively low species diversity is

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identified at the middle periphery of the lagoon. Spatial differences of the floristic composition and the diversity reflect the salinity tolerance ability of the different mangrove species.

Keywords Mangrove • Salinity gradient and species diversity

17.1 Introduction

Sri Lanka is relatively a small island in size with only 65,610 km^2 of land. The background of its physical geography is highly varied, resulting in a unique and very significant diversity in faunal and floral species. Vegetation analysis have recognized 13 different floristic zones within the country (Ashton et al. 1997) having 3360 plants species belonging to 1070 genera and 180 families (Peeris 1975). The coastline of the island which is about 1760 km in length (Jayatissa 2012) supports highly productive marine ecosystems. There are 45 brackish water bodies found along the coast of Sri Lanka (Silva 1996) (Fig. 17.1). The Negombo estuarine lagoon is one of among them.

The present extent of mangroves of the island has been estimated between 4000 ha to over 10,000 ha (Jayatissa 2012). Since the tidal amplitude is very low in Sri Lanka, the distribution of mangrove forests are confined to a narrow inter tidal belt. These are associated with some of the lagoons and estuaries in the country, therefore are patchy in distribution (Karunathilake 2003) (Fig. 17.2). Mangrove forests in Sri Lanka are found mainly along the northern, north-eastern, north-western and eastern coasts bordering lagoons and river estuaries (De Silva and De Silva 1998 and Jayatissa 2012). Twenty-five true mangrove species of trees and shrubs have been recorded in Sri Lanka, the common species being *Rhizophora mucronata*, *Avicennia marina*, *Excoecaria agallocha*, *Acanthus ilicifolius*, *Lumnitzera racemosa*, *Sonneratia caseolaris*, *Bruguiera gymnorhiza* and *Aegiceras corniculatum. Rhizophora mucronata* is more common in the dry zone where as *Rhizophora apiculata* is more common in the wet zone. *Bruguiera sexangula* is more common in the wet zone where as *Bruguiera cylindrica* is more common in the dry zone (De Silva and De Silva 1998; Karunathilake 2003). It is difficult to give a clear limit for the mangrove associates as the composition of them could vary depending on the edaphic and climatic factors of the habitats (Jayatissa 2012). The rare species are *Ceriops decandra*, *Sonneratia apetala*, *Lumnitzera littorea*, *Scyphiphora hydrophyllacea* and *Cynometra iripa*, of which the first three are endangered species in Sri Lanka (De Silva and De Silva 1998). There are no any endemic species among actual mangrove species or mangrove associates in Sri Lanka (Jayatissa 2012).

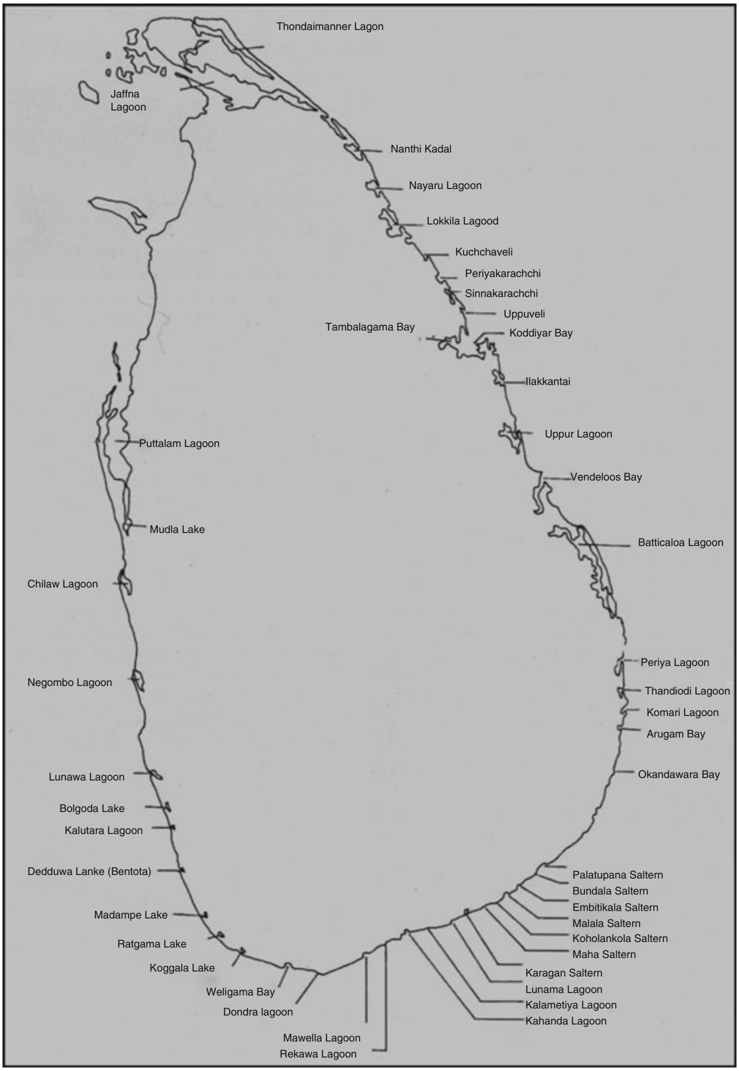


Fig. 17.1 Distribution of basin estuaries and lagoons in Sri Lanka (Source: Costal Conservation Department (CCD), 1996)

17.1.1 Negombo Lagoon and the Importance of the Study

The study was conducted in the Negombo lagoon located in the Gampaha District of Sri Lanka (Fig. 17.3). It has an area of 3164 ha and is situated about 40 km north of Colombo. The lagoon is part of the Muthurawajawela Marsh-Negombo estuarine lagoon coastal wetland (Central Environment Authority 1994). The estuary is a tidally influenced coastal wetland and links to the sea by narrow canals to the north,

Fig. 17.2 Mangrove areas in Sri Lanka (Source: http://2.bp.blogspot.com/ (25.01.2015))

close to Negombo town (Hettiarachchi and Samarawickrama 2011). Fresh water enters from the southern end of the lagoon through Dandugam oya, Ja-ela and several streams from the Muthurajawela marsh (Fig. 17.3). The supply of fresh water varies from virtually zero during the dry seasons to more than 100 cu ms during rainy seasons (Hettiarachchi and Samarawickrama 2011).

According to the generic classification of lagoons and lakes of Sri Lanka, the Negombo lagoon classified as a lagoon under “spit/barrier beach formation” category (Swan 1983). It is approximately 12.5 km in length and its width varies from 0.6 to 3.6 km. The average depth of the lagoon is estimated to be approximately

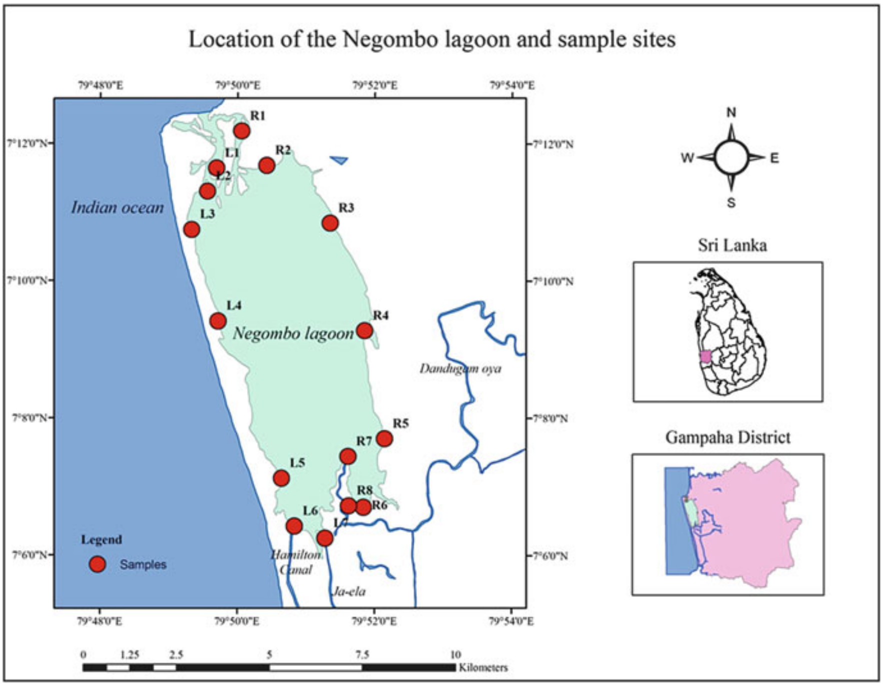


Fig. 17.3 Location of Negombo lagoon and sample sites

0.65 m and the surface area to be 35 km^2, thus placing its volume to be of order of 22.5 million m^3 (Hettiarachchi and Samarawickrama 2011). The lagoon is considerably chocked on tidal frequencies because of a narrow entrance (Rajapaksha 1997).

Tidal inflow of sea water occurs twice daily into the system (Kahawita and Vaithialingam 1954 and Central Environment Authority 1994). Thus, volume of water stored and release varies between 2.5 and 7 million m^3 per tide (Hettiarachchi and Samarawickrama 2011). The tidal range is 0.07 m at neap to 0.2 m at spring. The estimated 1300 million m^3/year of sea water are entering the area; mainly through the inlet of Negombo lagoon and about 70 million cu m^3/year through Hamilton canal (Environmental profile of Muthurajawela and Negombo lagoon, 1991).

Together with Negombo lagoon, Muthurajawela wetland ecosystem claimed for high biodiversity and ecological significance. So that the ecosystem is listed as 1 of the 12 priority wetlands in Sri Lanka (Emerton and Kekulandala 2003). It is unlikely to see natural forest vegetation except mangroves in the watershed (Silva 1996). Mangrove forests extend over a very narrow intertidal area on the edge of the Negombo lagoon, covering approximately 350 ha (Environmental profile of Muturajawela and Negombo lagoon 1991). Different authorities are responsible for mangrove coverage in the Negombo lagoon (Fig. 17.4).

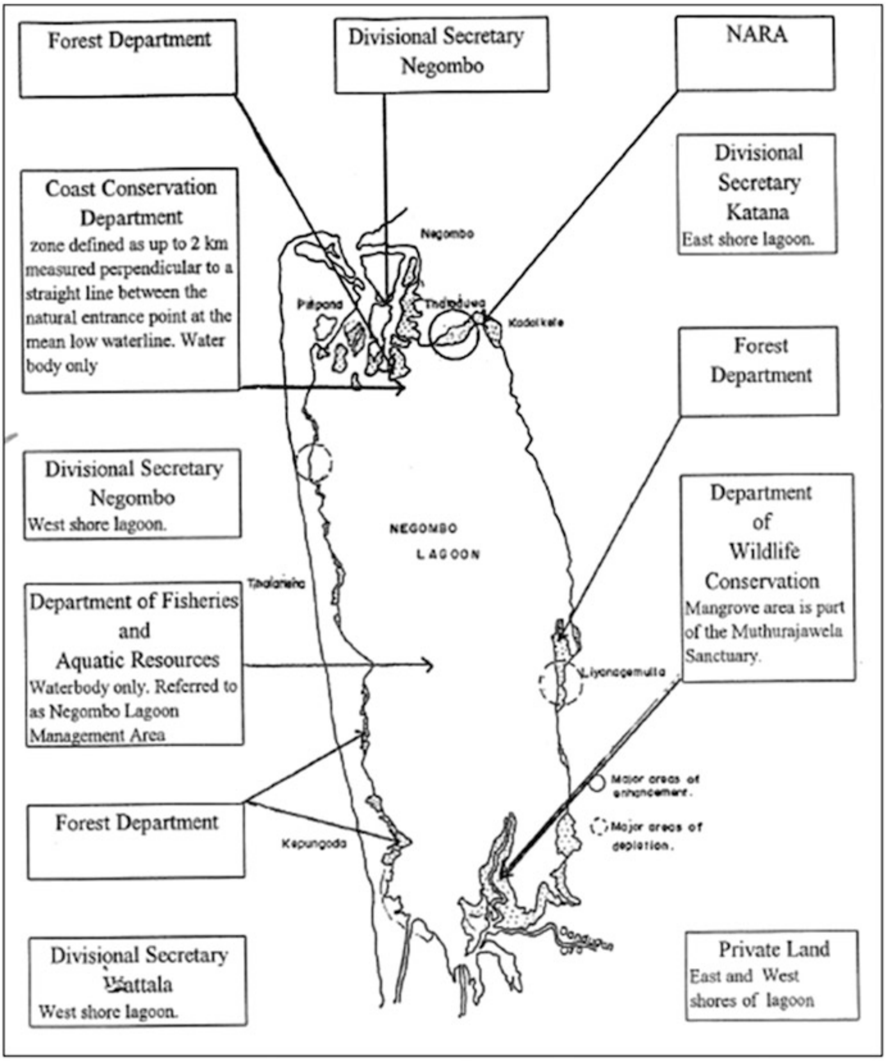


Fig. 17.4 Overview of the mangrove areas and department, agents, divisional secretariat and institutions involve (Source: Forest department and Central Environment Authority (CEA) Sri Lanka 2000)

(i) The Divisional Secretariat – Negombo, Wattala, Ja-ela and Katana
(ii) The department of wildlife conservation
(iii) The forest department
(iv) The Cost Conservation Department
(v) The Department of Fisheries and Aquatic Resources

Along the eastern lagoon shore most of the former mangrove forests has disappeared. On the recently immerged islands, mangrove species are being planted by local people for reclamation purposes, but these will be cut again once the soil has stabilized. The mixed vegetation of the brackish water swamp just south of the Negombo lagoon contains sedges, reeds and ferns associate with typical mangrove species (Environmental profile of Muturajawela and Negombo lagoon 1991).

Negombo lagoon is situated in an area with immense anthropogenic pressure. It suffers from inappropriate land use and unsustainable activities in the surrounding areas. Anthropogenic activities and the development of urban centers on both sides of the Negombo Lagoon are prominent causes for this stress (Katupotha 2012). Establishment of the Ekala industrial city and Katunayake free trade zone may have direct or indirect impacts on the water quality of the Negombo lagoon (Silva 1996). Cutting of mangroves for brushpiles fishing and other purposes continues unabated. Thus, human impact on the mangrove gives reason for concern, the main threat being the cutting of twigs and branches (Environmental profile of Muturajawela and Negombo lagoon 1991). Therefore, there is an urgent need to make a meaningful assessment of the water quality of the Negombo lagoon prior to implementing regulatory measures in order to maintain the quality of water and to conserve its flora and fauna (Silva 1996). Significant gaps still exist in the understanding of the ecology of the mangrove systems and hence recommended to continue studies on mangroves aiming protection, conservation and sustainable use (Jayatissa 2012).

In the present study an investigation was carried out to identify and assess the distribution pattern of mangrove species diversity across salinity gradient in Negombo estuary which will be timely important. The findings will help to disclose fundamental differences in species richness, diversity and assembly of plant communities along the salinity gradient. The results will be important to guide the management and make restoration plans in future conservation activities in the study area.

17.1.1.1 Objectives of the Study

(i) Collect phytosociological data of mangrove species
(ii) Find out species diversity and abundance species in the study area
(iii) Assess the spatial differences of species diversity with respect to salinity gradient.

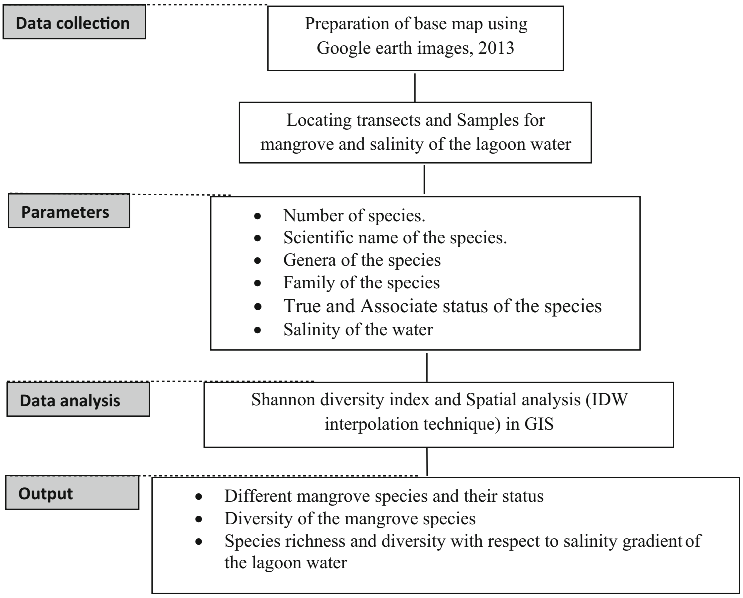


Fig. 17.5 Methodology and expected outcomes

17.2 Methodology

The study was basically depending on primary data collected by a field survey for identification of mangroves and testing of salinity in water of the Negombo lagoon. Summary of the methodology and expected outcomes of the study are summarized in Fig. 17.5.

17.2.1 Data Collection

17.2.1.1 Mangroves

The mangrove area was divided into two main zones namely Left (L) and Right (R) peripheries, according to the density of the mangrove forests based on the interpretation of a Google earth images in 2013. Vegetation sampling was carried out in two transects within each zone (Fig. 17.3 and Table 17.1) and the sample size is 5 m × 10 m. Fifteen samples were selected maintaining distribution of species heterogeneity. Only mangrove species were enumerated.

Specimens of the mangrove species were submitted to the National Herbarium of Sri Lanka in Peradeniya to identify the species and obtained their certification. Apart from that, species in the NARA site also were observed. Locations of the

Table 17.1 Details of vegetation transects

Transect	Number of samples	Symbol of samples
Left	07	L1-L7
Right	08	R1-R8
Total	15	

sampling sites of both mangrove and water were recorded using a 'Magellan eXplorist 610 handheld' GPS (Global Positioning Systems) receiver.

17.2.1.2 Salinity of Water

In situ field-testing of salinity was carried out at monthly intervals during October 2012 to September 2013 for 15 samples. Testing of water was carried out at same locations (Fig. 17.3) where the mangrove species were enumerated. A Ruttner water sampler was used to collect undisturbed water samples. A portable YSI −63 pH and salinity multi-parameter was used to check salinity measurements (ppt).

17.2.2 Data Analysis

Shannon-Wiener diversity index was calculated to compare the spatial diversity of mangrove species. Shannon index accounts for abundance and evenness of the species present. Results of the index are generally between 0 and 3.5 in most studies. Higher the value of the H, the higher the diversity. The value of H is low where low species diversity exists in a particular community.

$$H = -\sum_{j=1}^{s} p_i \ln p_i$$

Where, H is Shannon's diversity index, Pi is the proportion of the individuals found in the i th species, S is the total number of species in the community (richness) and *ln* is the natural logarithm.

Shannon's equitability (E_H) can be calculated by,

$$E_H = H/H_{max} = H/\ln S$$

Where, E_H is equitability (evenness), H is Shannon's diversity index and H_{max} is the maximum value of H. Value of the (E_H) ranges between 0 and 1. The higher the value indicates the less variation in the community between the species. Results are presented in the form of tables, graphs and maps.

The Inverse Distance Weighted (IDW) interpolation technique in ArcGIS was performed to prepare spatial distribution maps of mangrove diversity and abundance. Data analysis was accomplished using ArcGIS (version 9.3) software package along with Microsoft Excel.

17.3 Results and Discussion

17.3.1 Phyto-sociological Information of Mangrove Species in the Negombo Lagoon

Total numbers of 367 mangrove individuals were enumerated during the survey. Altogether there are 18 mangrove species identified belonging to 14 genera and 12 families. Among them 14 species are "True" and four species are "Mangrove Associates" (Table 17.2).

Table 17.2 Mangrove species of periphery of the Negombo lagoon

No	Species	Genera	Family	True/ associate
1	*Avicennia officinalis* L.	AVICENNIA	AVICENNIACEAE	True
2	*Avicennia marina* (Forssk.) Vierh.	AVICENNIA	AVICENNIACEAE	True
3	*Lumnitzera racemosa* Willd.	LUMNIZERA	COMBRETACEAE	True
4	*Excoecaria agallocha* L.	EXCOECARIA	EUPHORBIACEAE	True
5	*Xylocarpus granatum* Koenig	XYLOCARPUS	MELIACEAE	True
6	*Aegiceras corniculata* (L.) Blsnco	AEGICERAS	MYRSINACEAE	True
7	*Acrostichum aureum* L.	ACROSTICHUM	PTERIDACEAE	True
8	*Sonneratia alba* J.Sm	SONNERATIA	SONNERATIACEAE	True
9	*Sonneratia caseolaris* (L.) Engl.	SONNERATIA	SONNERATIACEAE	True
10	*Ceriops tagal* (Perr.) C.B. Rob.	CERIOPS	RHIZOPHORACEAE	True
11	*Rhizophora apiculata* Blume	RHIZOPHORA	RHIZOPHORACEAE	True
12	*Rhizophora mucronata* Poir.	RHIZOPHORA	RHIZOPHORACEAE	True
13	*Bruguiera gymnorhiza* (L.) Savigny	BRUGUIERA	RHIZOPHORACEAE	True
14	*Bruguiera sexangula* (Lour.) Poir.	BRUGUIERA	RHIZOPHORACEAE	True
15	*Acanthus ilicifolius* L.	ACANTHUS	ACANTHACEAE	Associate
16	*Cerbera odollam* Gaerth	CERBERA	APOCYNACEAE	Associate
17	*Dolichandrone spathacea* (L.f.) K. Schum	DOLICANDRONE	BIGNONICCEAE	Associate
18	*Hibiscus tiliaceus* L.	HIBISCUS	MALVACEAE	Associate

Source: Field survey, 2014

The largest numbers of representation of individual species (91 %) from the total are from "true" mangrove species. *Rhizophora mucronata*, *Rhizophora apiculata*, *Avicennia officinalis*, *Excoecaria agallocha and Acrostichum aureum* are the most common species in the in the Negombo lagoon area. These species represented about 71 % from the total individuals. AVICENNIA, SONNERATIA, RHIZOPHORA and BRUGUIERA claim for the most common genera in the lagoon. The highest widespread family is RHIZOPHORACEAE (Table 17.2).

17.3.2 Salinity Variations of the Negombo Lagoon

The average salinity levels of the lagoon water were between 5.3917 and 24.9917 ppt. The highest salinity values of the lagoon existed in October 2012 and the lowest in November 2012 which was closely linked to the rainfall availability during the study period. Spatially, the highest salinity was recorded at the northern tip of the lagoon outlet. Salinity showed a decreasing trend towards the southernmost end during the study period (Fig. 17.6).

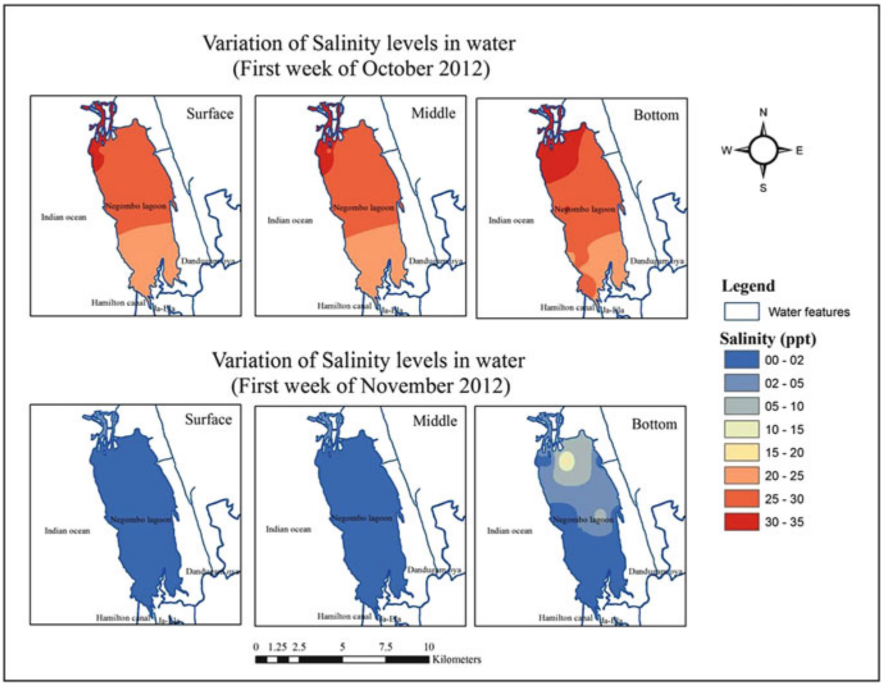


Fig. 17.6 Spatial distribution of salinity in the first week of October and November 2012 (Source: Chandrasekara et al 2014)

A pronounced salinity gradient was developed up to 7.75–8.5 km towards head of the lagoon from the lagoon outlet in both surface and middle water layers while the gradient reached up to 12 km in the bottom water layer during the low precipitation period. Both surface and middle water layers of the lagoon depict freshwater characteristics in salinity and one third of the bottom water layer from the head of the lagoon towards the outlet showed freshwater characteristics during the high precipitation period (Chandrasekara et al. 2014) (Fig. 17.6).

17.3.3 Spatial Differences of Floristic Diversity and Abundance Species with the Salinity Gradient.

Details of species diversity and abundance are shown in the Table 17.3 and the spatial variation of the diversity and abundance depict in Figs. 17.7 and 17.8. Spatially the highest mangrove species diversity can be identified in the southern quarter of the lagoon close to the inlet and a small patch around the outlet. Relatively low species diversity is identified at the middle periphery due to different land use practices and high level of human disturbance (Fig. 17.7 and Table 17.3).

It was identified that "true" mangroves usually establish in the intertidal shores (close to the outlet) of the lagoon and inlet of the lagoon is nourished with both actual and associate mangrove species (Figs. 17.7 and 17.8). The highest species diversity represents at the outlet due to the highest number of true mangrove species types. The highest diversity around the inlet due to both true and mangrove associates types. Considering the distribution of the composition of true mangrove species, the highest number of individual species of *Rhizophora mucronata* could be identified towards the outlet of the lagoon and the highest number of *Rhizophora apiculata* spread towards the inlet of the lagoon. *Excoecaria agallocha* were commonly found in the middle area of the periphery. *Acrostichum aureum* are

Table 17.3 Mangrove species diversity and abundance

Left bank			Right bank		
Sample	Diversity	Abundance	Sample	Diversity	Abundance
L1	1.6506	0.8482	R1	1.0079	0.7270
L2	1.2179	0.6744	R2	1.3667	0.8492
L3	1.1324	0.8047	R3	0.9448	0.6815
L4	0.6604	0.6057	R4	1.0889	0.7855
L5	0.2403	0.3467	R5	1.6326	0.9112
L6	1.5278	0.7851	R6	1.5630	0.9711
L7	0.9251	0.8421	R7	1.7266	0.8840
			R8	1.6716	0.9329

L1 Towards outlet, *L7* towards inlet, *R1* towards outlet, *R8* towards inlet

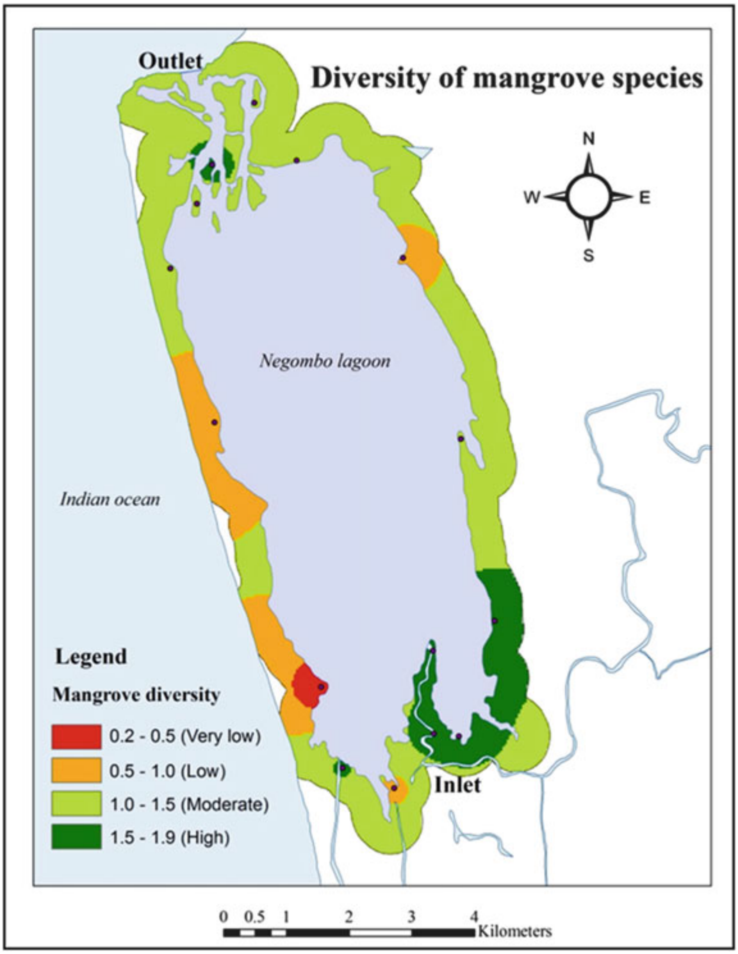


Fig. 17.7 Spatial variation of mangrove species diversity. One kilometer arbitrary buffer for the periphery of the lagoon were prepared to show the spatial variations of the mangrove species (Source: Field survey 2013)

widespread towards the middle and southern region of the lagoon, especially towards the decreasing trend of the salinity gradient (Figs. 17.6, 17.7 and 17.8)

Aegiceras corniculata, *Aegiceras corniculata*, *Bruguiera sexangula* and *Xylocarpus granatom* are the least common true mangrove species types found in the Negombo lagoon. *Xylocarpus granatom* is the sole species recorded in the sample number 14 (Table 17.3).

Avicennia officinalis, *Xylocarpus granatum*, *Sonneratia alba* and *Ceriops tagal* are highly restricted to the high saline area around the lagoon mouth (Table 17.3, Figs. 17.6, 17.9 and 17.10). *Sonneratia alba* is clustered at the outlet area of the lagoon while *Sonneratia caseolaris* was limited to the inlet area of the lagoon.

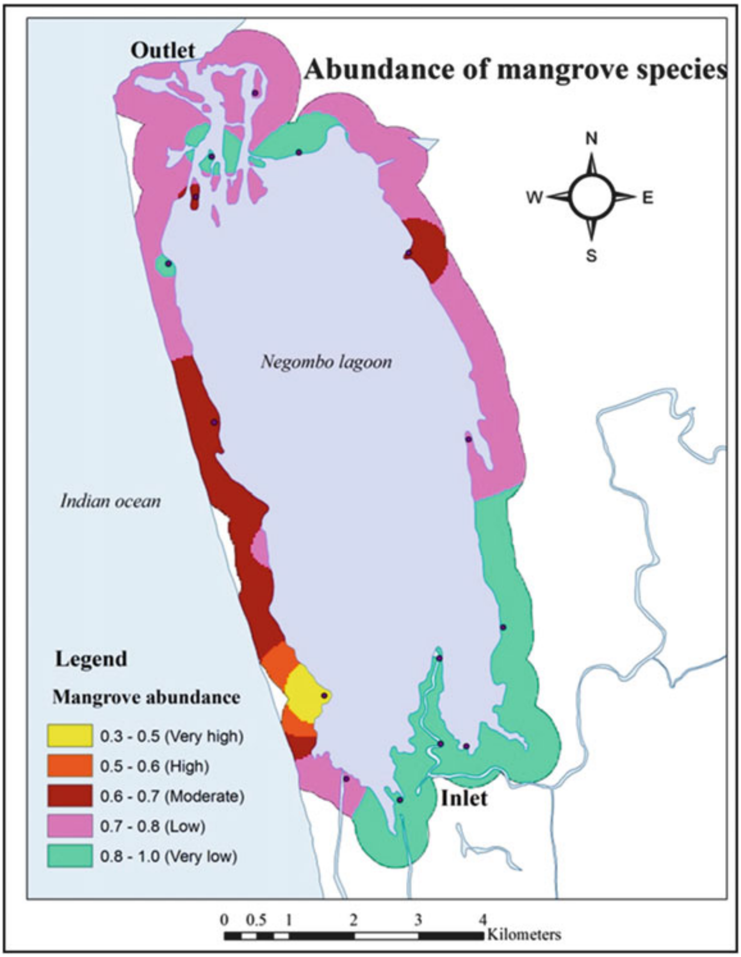


Fig. 17.8 Spatial variation of abundance of species. One kilometer arbitrary buffer for the periphery of the lagoon were prepared to show the spatial variations of the mangrove species (Source: Field survey 2013)

Sonneratia alba prefers high saline water and soil (A field guide, 2007). *Sonneratia caseolaris* is a freshwater (salinity below 10 ppt) loving species (De silva and De silva 1998 and A field guide, 2007) although both species are belong to the genera *Sonneratia*.

Four mangrove associate species namely *Acanthus ilicifolius*, *Cerbera odollam*, *Dolichandrone spathacea* and *Hibiscus tiliaceus* are only found in the southern most region of the lagoon which has highest species diversity. These species establish their habitats towards the proximity of the freshwater sources and towards the less tidal influence (Figs. 17.6, 17.7, 17.9, 17.10 and Table 17.4).

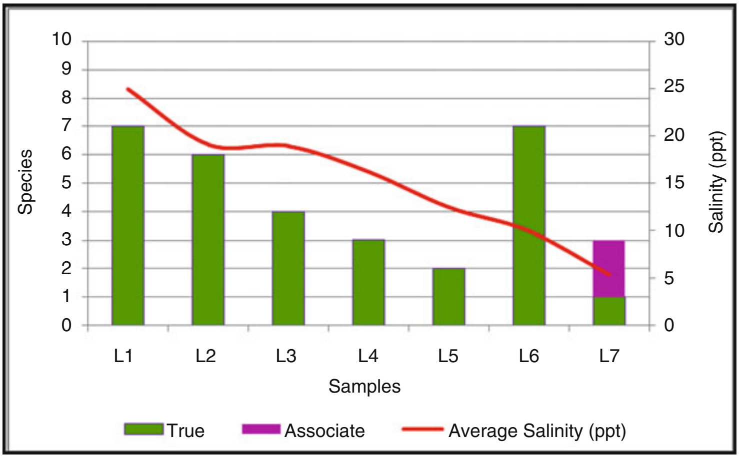
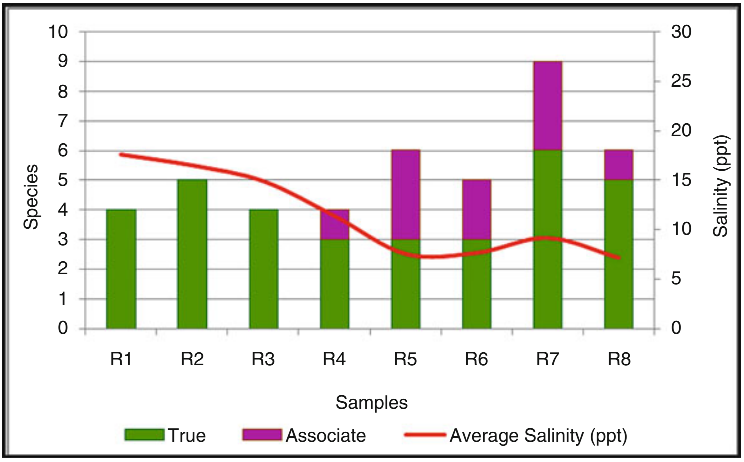


Fig. 17.9 Distribution of different species types with salinity gradient in the left bank



Source: Field survey 2012 and 2013

Fig. 17.10 Distribution of different species types with salinity gradient in the right bank (Source: Field survey 2012 and 2013)

Left periphery of the lagoon comparatively shows a low species diversity (Fig. 17.9) and high species abundance (Fig. 17.10). *Rhizophora mucronata*, *Rhizophora apiculata*, *Avicennia officinalis* and *Excoecaria agallocha* are highly dominate in the floristic composition of the left periphery.

Influence of *Annona glabra* is an invasive species that represented the highest number of individuals in Muthurajawela marsh, was identified close to the inlet of the lagoon which connects with Muthurajawela marsh.

Table 17.4 Distribution of different species

No	Species	True/associate	Samples														
			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	*Avicennia officinalis* L.	True	X	X												X	X
2	*Avicennia marina* (Forssk.) Vierh.	True			X			X									
3	*Lumnitzera racemosa* Willd.	True		X				X								X	
4	*Excoecaria agallocha* L.	True	X	X		X		X		X				X	X		
5	*Xylocarpus granatum* Koenig	True														X	
6	*Aegiceras corniculata* (L.) Blsnco	True									X						
7	*Acrostichum aureum* L.	True			X			X	X	X	X		X	X	X		
8	*Sonneratia alba* J.Sm	True	X														X
9	*Sonneratia caseolaris* (L.f) K.Schum	True								X							
10	*Ceriops tagal* (Perr.) C.B.Rob.	True	X	X													
11	*Rhizophora apiculata* Blume	True	X	X	X	X	X	X			X	X			X	X	X
12	*Rhizophora mucronata* Poir.	True	X	X	X	X	X	X		X	X	X	X	X	X	X	X
13	*Bruguiera gymnorhiza* (L.) Savigny	True	X					X		X	X	X	X				
14	*Bruguiera sexangula* (Lour.) Poir.	True									X						
15	*Acanthus ilicifolius* L.	Associate								X		X					
16	*Cerbera odollam* Gaerth	Associate							X		X		X				
17	*Dolichandrone spathacea* (L.f.) K. Schum	Associate									X	X	X				
18	*Hibiscus tiliaceus* L.	Associate							X		X		X	X			

17.4 Conclusion

There are 18 mangrove species identified belonging to 14 genera and 12 families. Among them 14 species are "True" and 4 species are "Mangrove Associates". The highest species diversity could be identified in the southern most region of the lagoon where the low salinity of water exists and the small islands of the lagoon outlet. On the left side of the lagoon periphery shows comparatively low species diversity.

Results of the study proved that the most common mangrove species types in the Negombo lagoon are *Rhizophora mucronata*, *Rhizophora apiculata*, *Avicennia officinalis*, *Excoecaria agallocha and Acrostichum aureum* and the least common true mangrove species types are *Aegiceras corniculata*, *Aegiceras corniculata*, *Bruguiera sexangula* and *Xylocarpus granatom* are. Abundance of associate mangroves is comparatively high towards the inlet of the lagoon while the actual mangroves dominate towards the outlet of the lagoon. Mangrove associates establish their habitats towards the proximity of the freshwater sources. *Xylocarpus granatum* is the sole species recorded in the study.

Spatial differences of the floristic composition and the diversity reflect the salinity tolerance ability of the different mangrove species.

It was observed that the periphery of the Negombo lagoon is severely disturbed by different types of anthropogenic activities. Thus, the mangrove species in the area are highly vulnerable for degradation. Practical implementation of conservation measures and sustainable methodologies for utilization of them is urgently required.

Acknowledgement National Herbarium, Peradeniya, Sri Lanka.

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Chapter 18
Nepal: Urban Environment Analysis

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Abstract It is argued that urbanization offers significant opportunities to reduce poverty and to promote sustainable development in Nepal, which is still at an incipient level of urbanization. Yet, there is tremendous pace of urban growth, resulting in multiple infrastructure and environmental challenges and there have been numerous efforts over the years to manage urban areas. This paper intends to analyse urban environment and its challenges and consequences, based on available data and substantiated it with three case cities. Finally, the paper provides some urban policy measures for intervention to ensuring sustainable and inclusive growth and development of urban areas in Nepal.

Keywords Land use • Urbanization • Environmental degradation • Slums and squatter • Urban policy

18.1 Introduction

Urban environment is a growing concern of urban management in developing countries. It is often related to rapid urbanization. It is widely asserted by the urban planners and policy makers across the developing world that the haphazard and uncontrolled growth of the cities generally invites many environmental problems, putting enormous pressure on limited resources and infrastructure as well as on finite land of the urban areas though rapid urbanization in itself is not necessarily a problem, as it promotes economic and social activities both in the cities and the city region.

Many of the urban environment improvement interventions in developing countries focus on managing wastes, quality water supply, sanitation, air quality, slums, etc., though managing against the largely affected urban land uses by the haphazard urbanization is the most challenging work with the city government.

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18.2 Data and Methods

The data and information drawn for the environment analysis of urban areas (or municipalities) of Nepal are based on the decennial population censuses and existing studies. In so doing, this paper intends to describe urban features, urban environment and land use patterns, urban plans and policies towards initiatives for urban environmental management, urban environment case study, discussions, and conclusion. Case analysis of three urban areas, viz Kathmandu, Pokhara, and Biratnagar representing different geographical regions across Nepal has been carried out for detailed urban land use change and their factors.

18.3 Nepal's Urban Features

The urban features of Nepal that shape the urban environment are described based on growth and distribution of urban places, urban economic base, social context of urbanization, urban infrastructure and services, urban poverty, urban finance, and urban institutional framework.

18.3.1 Growth and Distribution of Urban Places

Nepal is one of the least urbanized countries in South Asia. The level of urbanization is mere 17.1 %, but it is the fastest urbanizing country. The average annual urban growth rate is 3.38 % (CBS 2012). This is considered to be a rapid rate for Nepal, because if the annual urban growth rate continues at 3 %, by 2045 one-third of the country's population is estimated to be living in urban areas (UNDESA 2012). Throughout the decennial censuses from 1952 to 2011, the urban growth rates have always remained higher at 3.23–7.55 % than the national population growth rates at 1.35–2.62 % (Fig. 18.1).

This low level of urbanization is a matter of considerable concern for the spatial integration of different sized settlements, as well as for economic social, and administrative transformation in the country, while the rapid urbanization manifests distinctive characteristics and particularly the environmental problems that demand urgent attention. If well-planned, rapid urbanization can be an encouraging trend – it is a driving force for modernization, economic growth and development; it provides employment and reduces discrimination between advantaged and disadvantaged social groups. But the process of urbanization in Nepal is different. It is not due to economic reason rather it is caused by the expansion of municipal boundaries, designating new municipalities,[1] and the high level of urban-bound migration. The

[1] Currently, the number of municipalities is 191, adding up of 133 new municipalities in three times after the 2011 population census, which comprise town centers with their large tracts of rural surroundings. But the data on population and other urban features of those newly inducted municipalities are yet to ascertain.

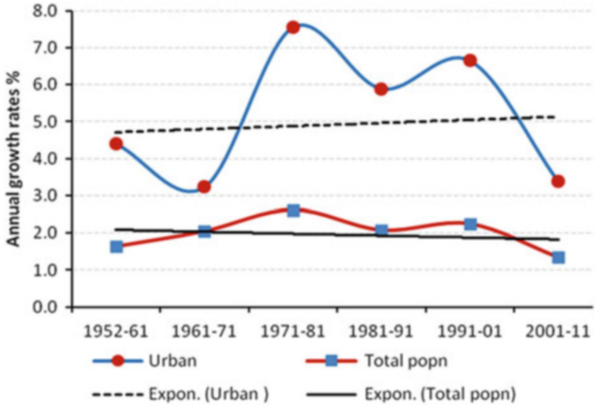

Fig. 18.1 Growth trends of population

availability of relatively better facilities than in rural areas draws people to municipalities. The recent trend is that when people migrate, they choose larger cities instead of small towns. Thus, bigger cities continue to grow faster than small towns putting more pressure on available resources, infrastructure and facilities and above all, the urban land resource and environment because they have grown mostly at the cost of consuming fertile arable land. The implications of rapid urbanization for employment, water supply and sanitation, and waste disposal produced by cities are staggering. In Nepal as cities grow, managing them becomes increasingly complex, showing formidable challenges. The key challenge is how to foster sustainable urban planning by means of providing basic urban services such as housing, drinking water and sanitation, preserving environment and prime agricultural land from haphazard urban encroachment, and controlling growth of slums and squatters. The current rate of urban growth and the consequent land use change if left unabated or unchecked leads to the major complexities for the future generations.

There are 58 municipalities or so-called 'urban areas' dispersing across Nepal.[2] The urban areas are divided into three hierarchical levels, viz metropolis, sub-metropolis and municipality with their corresponding numbers of 1, 4, and 53. They are designated for governance purpose rather than for economic strengthening of the municipalities. The average urban density is 1381 persons/km^2, with ranging from 160 to 20,289 persons/km^2. Twenty-five municipalities have density below 1000 persons/km^2, while 6 municipalities with above 5000 persons/km^2.

The distribution of urban areas by size is uneven all over the country (Fig. 18.2). Ten large cities with population 100,000 and more share 54 %, while 31 small towns with population below 50,000 share 20 % of the total urban population

[2] In Nepal, urban areas are defined with the threshold population size of 10,000 for the hills and mountains and 20,000 for the Tarai (plain).

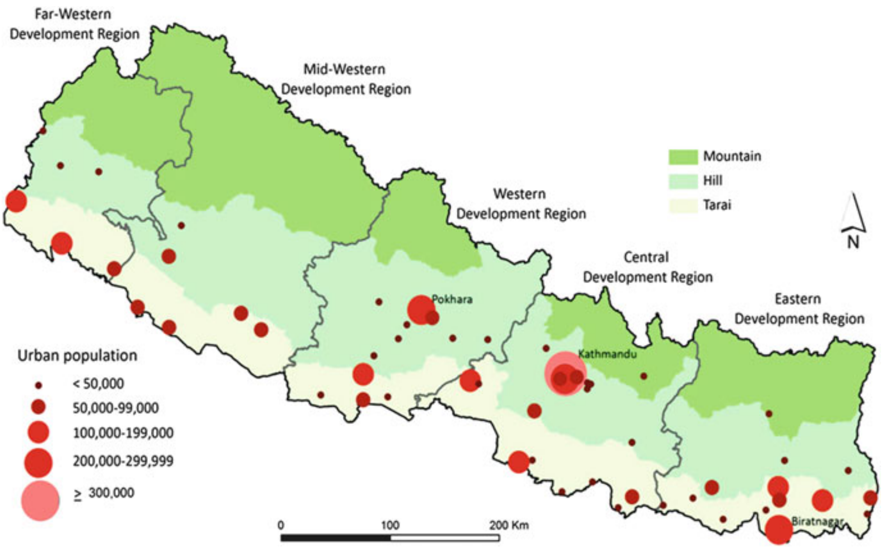

Fig. 18.2 Distribution of urban areas, Nepal, 2014

Table 18.1 Distribution of urban areas by size class, 2011

Class	Urban population range	Number of urban areas				Urban population	
		Tarai	Hill	Mountain	Total	Size	Percent
I	<50,000	12	17	2	31	902,890	20.0
II	50,000–99,999	10	7	0	17	1,182,522	26.1
III	100,000–199,999	6	0	0	6	738,455	16.3
IV	200,000–299,999	1	2	0	3	696,668	15.4
V	≥300,000	0	1	0	1	1,003,285	22.2
Total		29	27	2	58	4,523,820	100.0

Source: CBS (2012)

(Table 18.1). Of 10 large cities, 7 lie in the Tarai and the rest 3 in the central and western hills. The Hill and the Mountain regions also do have larger number of small towns. Likewise, the distribution of urban areas varies greatly among the development (longitudinal) regions. For instance 38 centers including Kathmandu, the largest metropolitan and 2 sub-metropolitan cities (Pokhara and Lalitpur) are concentrated in the central-west region.

However, the gap in distribution and size classes of the urban areas in terms of population sharing has narrowed down over the census years. As depicted in Table 18.1, the population shared by 'Class I' (smallest size) among the 5 urban size classes in 2011 is 20 % as against about 22 % by 'Class V' (largest size). In 2001, the smallest and largest groups shared about 36 and 21 % urban population respectively. But in both census years, there remained to be only one urban center, i.e.

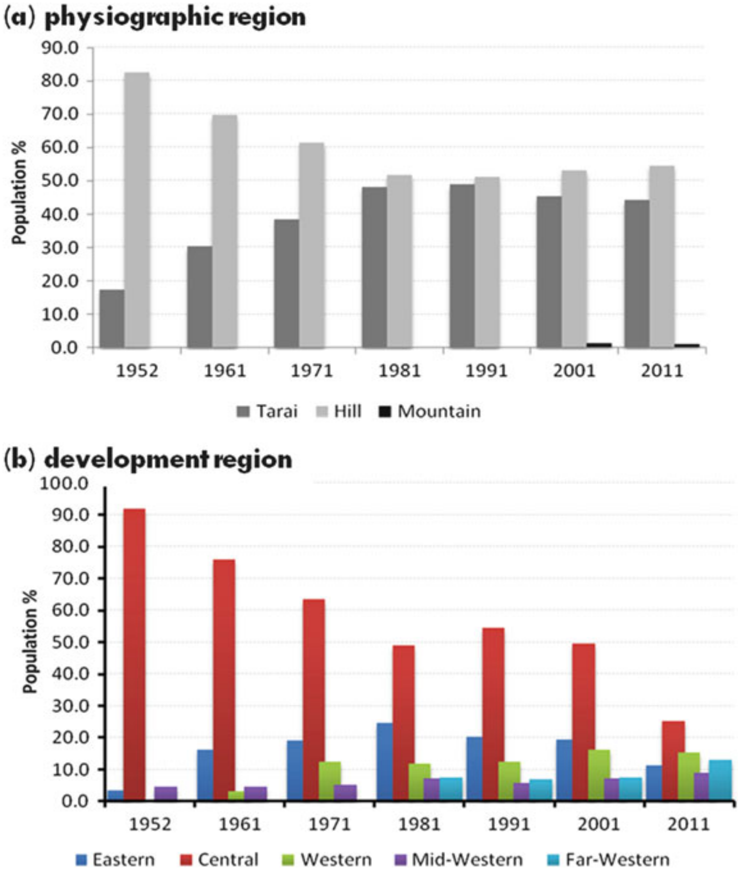

Fig. 18.3 Sharing of urban population by census years, Nepal

Kathmandu in 'Class V', indicating maintenance of its supremacy, while the number of urban centers associated to 'Class I' declined from 42 in 2001 to 31 in 2011. The gap of urban population by the physiographic (latitudinal or mountain/hill versus plain) and the development (longitudinal or east–west) regions has also gradually narrowed down over the years. For instance, sharing of urban population by the hill region declined from over 80 % in 1952 to 55 % in 2011, while that of the Tarai grew from below 20–48 % between the same two census years (Fig. 18.3a). But still 32 districts in the hill and the mountain regions are without a single urban area. Likewise, the gap in urban population among the development regions has reduced over the consecutive census years (Fig. 18.3b). In 1981 nearly 50 % urban population lived in the central region and that declined drastically to 25 % by 2011, giving more or less a fair sharing of urban population among the development regions.

Unbalance distribution of urban areas by different sizes throughout the country is a major hindrance to integrated regional development. It appears that there is short in the number of small sized urban places, if an array of hierarchical levels of the urban places for articulated urban system is maintained at the ratio of 1:3 (Christaller 1966). If the number of current higher order urban places is maintained, the number of lowest level centers should be increased to 54 across all regions of Nepal.[3]

This distinct uneven pattern of spatial distribution of the cities and towns has implications on urban–rural linkage development and environmental planning. Urban development in the hills and mountains of Nepal is hindered by rugged terrain, a maze of spurs and narrow valleys, scattered arable land, and difficulty of movement. Here, urban areas except in the Kathmandu and Pokhara valleys are small, widely dispersed and slow growing. The hill urban areas have to serve an average of 2272 km^2 surrounding hinterlands nearly twice the area, i.e. 1173 km^2 to be served by the Tarai urban centers. In the mountains, it is even larger, i.e. 25,909 km^2 hinterland areas to be served by an urban center. Though the hinterland areas to be served by urban centers in the mountains and hills are extensive, they in fact serve localized populations and immediate surroundings due to lack of road links, while scattered village settlements are too far away to make use of better urban amenities. There is lack of an appropriate national policy to address urbanization and urban bound migration, which are rising spontaneously. The resulting urbanization process is not slowing down, but it ignores basic infrastructure in certain geographical areas. For example, the transport network and other basic infrastructure are deficient throughout the mountain region and most of the hill region, where a considerable proportion of population lives in far-flung settlements without basic facilities and services and depends on traditional agriculture as a source of livelihood. In Nepal, urbanization and the consequent process of economic, social and even political changes that it entails has to be very much part of its development vision.

18.3.2 Urban Economic Base

Urban economy is a vital sector for overall development in Nepal. According to the World Bank's estimate (2011), the urban sector has contributed to about 62 % of total gross domestic product (GDP). The services sector in the urban areas accounted for 47 % of GDP, while the contribution of manufacturing to GDP remained at about 15 %. Likewise the urban sector shared 36 % of nonfarm employment, 28 % of manufacturing employment, and 39 % of service employment (World Bank 2013). But the economic base of both the services and

[3] As stated above (see footnote 1) the newly inducted 133 municipalities are small and consist of surrounding villages having dominant subsistence farming activity, which can be termed as 'urban village' (Pradhan 2004). This number gives too many or exceeds the suggested number of small urban places, which also means that number of larger centers should be increased.

manufacturing sectors is characterized by small wholesale and retail service and small-scale industries.

Yet, the economic base of the Nepalese municipalities is still rudimentary and weak. The primary production sector employs more than 50 % of the working population in 17 of 58 urban areas, meaning little scope to generate revenue and employment, while the trading and manufacturing sector has relatively low share, which indicates that urban areas largely export primary products and import finished products. Given the limited key infrastructure and facilities, the urban areas of the hill region, with the possible exception of the Kathmandu and Pokhara valleys, have extremely limited potential for industrial development. However, small and micro enterprises including trade and business, service sector and manufacturing dominate the urban economy. Informal activities also are increasing as cities grow and play important roles in providing livelihoods and services to the urban poor.

Poor urban economic base is also due to fact that potential development of agriculture and other natural resources such as forest, pasture, and water in the hills and mountains has not been achieved, while the Tarai's rich and fertile alluvial soils and tropical forests have not been fully exploited and its comparative advantages as a location for industry are stunted by limited infrastructure and facilities. In the rural areas, remittance is the second-largest source of income after farming, which can be a potential source of investment particularly in the large cities, since rural areas have limited potential for private investment.

18.3.3 Social Context of Urbanization

Large stream of urban-bound migration is one of the major causes of rapid and haphazard growth of urban areas in Nepal. Currently, the inflow of migrants to urban areas represents 45 %, compared with an outflow of 16 % of the urban population. During the 1990s, migration contributed 30 % to total urban growth (ADB 2010). Urban areas including large cities like Kathmandu, Pokhara, Birganj, Butwal, Bharatpur, etc. have grown over 60 % population in the 2000s whilst migration contributed 30 % to total urban growth (CBS 2003). Some urban areas had received migrants ranging from 40 to 57 % of their total population during that decade. The urban-bound migration has involved a large number of youth and youth unemployment has become a crucial problem in Nepal. A "brain drain" among the young people with higher education and skills is also an emerging economic problem (CBS et al. 2006). Furthermore informal land development is a common phenomenon. This together with an increasing number of squatter settlements mostly occupying idle lying lands along the riverbanks in fast-growing large cities is a conspicuous manifestation of rapid and haphazard urbanization. This is due to lack and/or un-implementation of urban land use plan or weak enforcement of public acts and laws by the municipal government to protect the public land and open spaces. While people in slum and squatter settlements live in the most vulnerable conditions, susceptible to river flash floods, the smell and nasty environment of dumping sites with extremely deficient water and sanitation, foot-loose vendors occupy busy city streets and footpaths, causing congestion and noise.

The cultural and religious significance and natural beauty of many of urban areas in Nepal attract domestic and international visitors, bringing important sources of revenue for municipal government. But the physical state of some monuments and sites and water bodies (ponds, lakes and sacred rivers) in the cities like Kathmandu, Janakpur, and Pokhara are deteriorating quickly due to haphazard growth, inefficient planning, wastes discharge, financial constraints, and lack of a buffer zone between urban dwellers and the renowned sites.

18.3.4 Urban Infrastructure and Services

Infrastructure is the main driver of urban economy, as it includes strategic assets such as basic and utility infrastructure (transport and communications, drinking water, electricity, sewerage system, waste management, etc.), buildings, and structures necessary for the production and delivery of the goods and services. Urban infrastructure is considered for two purposes: livability and competitiveness for urban economic growth.

Investment in urban infrastructure is essential for economic and social development. There is a close relation of infrastructure with municipal revenue, as well as with business dynamics. Studies by Wang and Davis (2005) showed that local government expenditures on highway, public safety, and utilities have positive relations with growth. In terms of financing local infrastructure, it is argued that a city's ability to raise its own source revenues by means of local taxes and user fees increases infrastructure supply. The supply of local infrastructure services, such as municipal roads, water supply and drainage, street lighting, etc. in turn enhance competitiveness, but their impacts are comparably much smaller (UDLE 2008). However, rapid urbanization is placing pressure on an eroding, ageing infrastructure, and raising concerns about declining air and water quality, mounting city wastes, and deteriorating roads. The cities with poor basic infrastructure are greatly disadvantaged when it comes to being competitive. To be competitive, the cities must learn to take a more demand-driven approach to economic development.

Identification of competitiveness of industries or businesses is important for urban areas to increase own revenue source and investment. There have been efforts in ADB study (2010) to identify infrastructure and products in urban areas of Nepal in terms of comparative advantage and competitiveness at international level. There are 18 types of indicators being identified, as most feasible for comparative advantage among the urban areas, the products competitively at international level comprising spices, tourism, carpet weaving, pashmina items, cut flowers, jewelry making, fruits, vegetables, dairy products, grains and cereals, poultry and fishing, and honey, and the infrastructure required for accelerating economic growth (ADB 2010). However, the infrastructure identified and required varies greatly by municipality, due to their location and resource potentials, but the most common are road and transport networks, electricity, skill and enterprise training, labor based industries, market expansion, extension services, research and development, and transport with refrigeration. Overall, the level of infrastructure available is fairly poor, below 50 %.

In Nepal, public capital expenditure in urban areas has different features. First, there is a mismatch between allocation of national expenditure to urban infrastructure and urban growth rates. In 2008, the allocation of national-level expenditure to the urban infrastructure was 18 %, slightly above the proportion of urban population (16 %) but in 2010, the urban share of national-level capital expenditures declined to 12 % while in the mean time the share of the urban population increased to over 17 %. Second, urban areas are the main recipients of project-based capital expenditures under national-level programs. In 2010, the project-based capital expenditure in urban areas amounted to US$2.7 per capita under national programs, as compared with only US$1.6 in rural areas. Third, public capital expenditure for municipal infrastructure now averaging US$11 per capita that was declined from US $14 per capita in 2008 which is already very low base, given urban areas' infrastructure requirement (World Bank 2013). Fourth, the municipal infrastructure is funded by three main sources of public investments, such as: (i) project-based programs financed by central agencies, which is the largest contributor, sharing about 49 % of total capital expenditure, (ii) inter-governmental fiscal transfer system as capital block grants, the second in row in terms of proportion sharing, and (iii) own-source revenues, the lowest at about 8 % of total capital expenditure. The project-based programs are the main form of infrastructure-financing modalities in the 53 municipalities, whereas blocks grants prevail in metropolitan (Kathmandu) and sub-metropolitan cities (Pokhara, Biratnagar, Lalitpur and Birganj). On a per capita basis, the municipalities benefit from a higher level of capital expenditure for municipal infrastructure than the metropolitan and the sub-metropolitan cities. For instance, the infrastructure (physical and social) capital expenditure averaged US $11 per capita in the 53 municipalities, due partly to a substantial presence of project-based investments funded by development partners, whereas in the metropolitan and sub-metropolitan cities, spending remained below US$ 3.0 per capita on average (2010 prices; World Bank 2013). The level of per capita expenditure on physical infrastructure projects is worrisomely low particularly in the sub-metropolitan cities, considering the critical role they play in driving economic growth in country's main extended urban economic regions.

So, the municipal governments in Nepal have given least attention to urban planning and management and its importance in urban economic development. Rapid urbanization is intensifying the municipal infrastructure deficit. Urban sector initiatives, as indicated by World Bank's study (2013), have taken 10.4 % of the total budget; the third biggest share after roads (48.2 %) and drinking water supply (13.4 %), however the latter two are somehow related to urban sector.

Thus, planning and provision of infrastructure and facilities has not kept pace with urban growth, meaning proliferation of unhealthy, poorly serviced and infrastructure-deficient sites, signifying as major constraints to economic growth and city competitiveness. Most municipalities are incapable of providing the required infrastructure and facilities adequately to cope with the growing demand because of insufficient financial and human resources, low institutional capacity, etc. Though the contribution of urban areas to the national economy is as large as three-fifths, its annual investment is only 2 %. Moreover, the spatial distribution of capital expenditure for municipal infrastructure is biased against Kathmandu, where infrastructure needs are the greatest (World Bank 2013).

Inadequate and poor quality infrastructure and facilities are key concerns of urban development. Intermittent electricity supply is a major impediment to the expansion of urban-based industrial development and yet not all urban households have access to electricity. Nepal has significant hydropower potential, and commercially exploitable hydropower generation is estimated to be roughly 43,000 MW. Despite this generation potential, only about 600 MW have been developed so far (ESMAP 2008). Inadequate and intermittent supply of water is a serious issue in most of the hill towns. The quantity delivered in many municipalities is below 50 l per capita per day, which however varies seasonally. Water quality in most urban areas is below the WHO standard for drinking and groundwater as major source of water in the Tarai urban areas is also being contaminated by arsenic (NRCS 2003). There is virtually no sanitary waste disposal system and functioning storm-water drainage system and solid waste systems are extremely inadequate. Urban road conditions are mostly in un-repaired condition, due to many potholes.

18.3.5 Urban Poverty

The current urban poverty incidence is 15.5 % as compared to 27.4 rural poverty and the current urban poverty has been decreased from 21.6 % over a period of 15 years in 1996 (CBS 2012). But the urban poverty incidence ranges vastly among the urban areas, with the lowest at 1.3–45.6%; the latter is quite high as compared to the national average poverty at 25.2 %. Fourteen municipalities fall below 10 % poverty incidence that comprises large urban areas of Kathmandu and Pokhara valleys and the fast-growing centers of the Tarai region, while 11 urban areas mostly small, newly inducted have poverty incidence above 30 %.

Urbanization is a main driver of poverty reduction, but one key issue in urban poverty in Nepal is the increased rate of in-migration in large urban areas, which suffer high unemployment and offer limited income generating sources. Nepal is still in the early stages of industrialization and urbanization. Government efforts appear unable to reduce poverty among the urban unemployed youths. Given current governance structures and systems, municipalities face a crucial challenge in implementing measures for poverty reduction and managing myriad petty informal employment activities amid increasing slums and squatter settlements in urban areas.

18.3.6 Urban Finance

The urban finance system in Nepal has evolved over the last two decades. Initially, *octroi* tax was the main revenue source, contributing almost two-thirds of the total municipal revenue. Later local development fund replaced it, which is the largest single revenue source contributing over one-third of total revenue. Again, local development fund is considered a temporary measure.

Internal sources are dominant, accounting for over three-fifths of total revenue of all municipalities. Of internal sources, property-based tax as the most sustainable source is increasing. This source comprising house and/or land and property, and professional taxes seems to be favorable for large urban areas where non-primary production activities and private sector dominate. In addition, the municipalities also get grants and loans as external sources from the central government, national and international financial institutions, and development agencies. Grants and loans account for over one-fifth of total municipal revenue. But however, revenue generation is an important issue for municipal government as lack of financial resources is a critical constraint on urban development. Strengthening the financial resources of municipalities is crucial for funding infrastructure.

A substantial portion of municipal spending with over two-thirds is used for capital investment in public infrastructure including land or building purchase, construction, and other developments like facilities for waste dumping sites, roads, embankments, community services, etc. In most municipalities that have relatively low economic activity due to limited private sector investment in economic development initiatives and urban services, total expenditure generally exceeds total revenue.

There is lack of competency and commitment in municipal government for mobilizing different revenue sources. Reducing most municipalities' dependency on the central government is a major challenge. Furthermore, mobilization of financial resources by municipalities is hampered by the lack of a sound financial management system – an accrual-based accounting system has not been established and is not in use in most municipalities.

18.3.7 Urban Institutional Framework

There exists basically two-tier governance structure, viz. central government and local or municipal government for the planning and management of urban areas in Nepal. At the central government there are two ministries – Ministry of Urban Development and Ministry of Federal Affairs and Local Development – dealing respectively with managing the development of urban areas and the financial and administrative operations of municipalities. Besides, there are some autonomous bodies to provide financial and technical support for infrastructure and revenue generating activities in the municipalities, as well as many central government agencies and statutory corporations for urban services delivery. However, none of these institutions has the technical capacity and human resource capabilities to analyze the on-going process of urbanization relative to overall development within a spatial context. The institutional and financial capacities of the municipalities to manage urban infrastructure and urban growth remain severely constrained.

The central level institutional framework for urban planning and management is quite complex and confusing. There are several overlapping and gray areas among these institutions' responsibilities for municipality planning and development. While the organizations working for the multiplicities create potential for duplication and competition among themselves, conflict provisions in different acts compound confusion. With so many institutions involved in the urban development, one crucial problem the urban areas facing is a challenge in coordinating their activities and thereby affecting the pace of urban development to move on a sustainable and economically vibrant way. Indeed, in many cases the ad hoc nature of designating urban areas and the considerable over-bounding to provide municipal status make it difficult to assess the true nature and character of Nepal's urbanization.

As per the Local Self-Governance Act 1999, the municipality is the local government body that is responsible for overall development of municipal towns and surrounding areas. But since 2002, the municipalities have remained without elected representatives and thus lacking of delivery of committed development works. Over two-thirds municipalities are resource-constrained in equipment, technical manpower, capacity building, and specialized human resources. Similarly, almost half the municipalities have insufficient budgets allocated for planning and management of the key infrastructure (World Bank 2013).

18.4 Urban Environment and Land Use Pattern

18.4.1 Urban Environment

The urban environment in Nepal has been degraded over the past few years. There are emerged a number of urban environmental issues, coupled with government inability to match needs with infrastructure and facilities. Haphazard development has taken place in areas prone to flooding and facilities-deficient sites in many large and emerging cities. Although environmental problems particularly in large urban areas including the Kathmandu Valley cities are considered more severe than in small urban areas, several fast growing and emerging municipal towns are also facing environmental problems. The problems are related to land, wastes, water, air, and noise pollutions, which in combination intensify their impact on the environment and the quality of urban life.

Managing haphazard growth in the urban areas remains difficult due mainly to the lack of land-use zoning plans and laws. Urban land is the most polluted due to uncontrolled urban growth, haphazard disposal of solid and liquid wastes, poor planning of urban services, and weak institutional effort to combat these challenges. Further, declining of prominent agricultural land to rapidly spreading urban blight and rising of squatter settlements are conspicuous manifestations of rapid and haphazard urbanization.

Solid waste management is one of the most pressing environmental problems of Nepalese urban areas. Large urban areas in particular face alarming environmental problems due to ever-increasing volume of waste and heaps of garbage usually in open spaces and riverbanks that often remain uncollected for days. Every day the municipalities generate 1350 t of solid waste (Pradhan and Pradhan 2006). Lack of dumping sites makes solid waste disposal a common problem in all 56 urban areas (except Pokhara and Ghorahi where wastes are being disposed in a sanitary landfill). Unmanaged solid waste significantly damages public health and harms monuments and renowned historical, cultural, and natural sites. Solid waste management has indeed become very costly for municipal government. Access to toilets in urban areas of Nepal is at 85 %, yet many toilets remain unsanitary. There is no sewerage facility in the urban areas, except the cities of Kathmandu Valley. This calls for further improvements. The urban water sources are also highly degraded because of discharge of untreated domestic, hospital and industrial wastewater into local water bodies and dumping of solid waste. These sub-standard services are an obstacle not only for city livability but also for sustainable economic development, including tourism.

Air pollution is deteriorating in major cities as vehicular and industrial emissions, dust, and burning of plastics increase. Managing the burgeoning traffic with respect to pedestrians has been a great challenge particularly in the cities of Kathmandu valley, where in the last few years, ailments relating to air pollution such as pneumonia, bronchitis, and asthma have been common. Indoor air pollution is also a problem, particularly for poor households in small urban areas due to burning of biofuels (firewood, cow dung, and crop residues) for cooking and heating.

18.4.2 Urban Land Use Patterns

Land use is a fundamental measure of how the environment is organized in a setting. Over time as the population changes, as the economy grows, and as the government infrastructure spreads, land use is likely to be transformed in many ways, for instance, the conversion of agricultural land to land for housing and other non-agricultural enterprises, the reduction of greenery lands, and the intensification of farm land (Axinn and Ghimire 2011). In Nepal, migration of population including both internal spatial shifts within the urban region and urban bound migration are a key driving force for urban sprawl causing changes in the land use patterns in fast growing cities (Pradhan 2003; Thapa 1996). The urban built-up areas range from below 5 % in the small urban areas to over 60 % in large urban areas. But yet particularly the emerging and newly inducted municipalities have more than half their urban areas covered either with agriculture or forest, due to over-bounding of rural areas. Urban land development through land pooling on a small scale has been concentrated in few major cities.

The municipal government, according to the Local Self Governance Act-1999 of Nepal, is responsible for preparing urban plans including periodic plan, poverty and resource maps, master plans, other plans, and land use plan delineating industrial, residential, agricultural, recreational, and other zones. The periodic plan usually for 5 years is to cover components like financial, physical development, water resources, environment and sanitation, education and sports development, culture, works and transport, health service and control of contagious diseases, social welfare, industry and tourism and their associated factors. Most municipalities lack these urban plans. The municipality has virtually no legal instruments to control land use development effectively. There is no legislation that defines land use classes, land use planning, zoning planning, or similar. In 1976, the central urban government had for the first time made land use zonation planning of 16 municipalities. But since then no land use zonation for the urban areas has been attempted to build.

18.5 Urban Plans and Policies

Planning for town development involves efforts to put together the human and physical resources to build a sustainable future of the towns. It is largely the formal responsibility of local and national governments.

The town planning in Nepal has evolved eminently over the past four and half decades. The early town planning initiatives in the late 1960s focused on physical development plans. Since the 1990s the integrated action plans remained as a major tool of town planning. In the 2000s and onward, the town planning constituted the strategic and periodic plans. Throughout the planning period, the government has continued efforts to build urban infrastructure, but these have lagged behind the rapid growth of urban population. The National Urban Policy (DUDBC 2007) proposes building the capacity of municipalities to plan and manage integrated local development activities and recognizes the investments being inadequate to the urban growths. This urban plan has stressed inclusive development and increasing public expenditure, building infrastructure, etc. Crucial challenges with the urban sector now include provision of basic infrastructure, and raising municipal revenue and mobilizing funds to respond to growing demands of urban infrastructure and managing haphazard and uncontrolled growth of urban settlements.

It appears that, all the past policies and guidelines were scattered and did not have an integrated policy framework to guide the urbanization process and to conserve the urban environment. There is not yet formulated a national urbanization policy for an immediate and measurable development impact that addresses the critical issue of seriousness of concern over the high level of urban-bound migration and rapid urbanization (Ertur 1994). The urban problems of Nepal

Table 18.2 Growth of urban population in three cities (1952–2011)

Year	Biratnagar		Kathmandu		Pokhara	
	Population	Percent	Population	Percent	Population	Percent
1952/54	8060	–	106,579	–	–	–
1961	35,355	338.6	121,019	13.5	5413	–
1971	45,100	27.6	150,402	24.3	20,611	280.8
1981	93,544	107.4	235,160	56.4	46,642	126.3
1991	129,388	38.3	421,258	79.1	95,286	104.3
2001	166,674	28.8	671,846	59.5	156,312	64.0
2011	204,949	23.0	1,003,285	49.3	264,991	69.5
Growth rate (1961–2011)		5.8		8.3		49.0

Sources: CBS different censuses

comprising unemployment, shortages of infrastructure, declining environmental quality, urban sprawl, increasing slums and squatters, and scarcity of financial resources for investment constitute formidable policy challenges (ADB 1991).

18.6 Urban Environment Case Studies

In Nepal, unplanned urban sprawl is on the whole a key characteristic of all urban areas. However, different urban areas present unique feature of urban growth, environment and infrastructure planning and management. Three cities – Kathmandu, Pokhara and Biratnagar – representing the urban areas of Nepal are cited here as case study. Kathmandu representing the central hill region is the metropolitan capital and the largest and highest density city, while Pokhara and Biratnagar represent respectively the western Hill region and eastern Tarai and border region and currently are second and fourth largest sub-metropolitan cities (Table 18.2).

At the national context of urban growth rate, two cities – Kathmandu and Pokhara – have higher growth rates, but Biratnagar has slower growth rate. During the past five decennial censuses from 1961 to 2011, the urban population grew by about 6 times for Biratnagar and slightly over 8 times for Kathmandu while that for Pokhara by 49 times. There is consistent increase in the urban population in all three cities during the past five decades, but with varying average growth rates, viz. 94 % for Biratnagar, 47 % for Kathmandu and 129 % for Pokhara. These growths are due to malaria eradication program in the late 1960s, amalgamation of surrounding village areas into the respective municipalities, urban bound migration and other development activities.

The urban growth rates of Kathmandu and Pokhara are higher than the national average urban growth rate in 2001–2011, but in 1991–2001 the growth rates were less in all the three case cities than the national urban growth rate (Table 18.3).

Table 18.3 Urban population of three case cities, Nepal (1991–2011)

Case cities	Population growth rate		Area (km^2)	Density persons/km^2
	1991–2001	2001–2011		
Kathmandu	4.7	4.0	49.5	20,289
Pokhara	4.9	5.7	55.2	4818
Biratnagar	2.5	2.1	58.5	3505
Country total	6.4	3.4		1381

Sources: CBS (2012, 2002, 1993)

18.6.1 Kathmandu

Kathmandu Valley lies in the central hill region of Nepal and extends over 19 by 25 km. The bowl shaped valley is a tertiary structural basin covered by fluvial and lacustrine sediments and encircled by mountains on all sides with above 1800 m high and the valley floor has an average elevation of about 1300 m from the mean sea level. The valley lies in the temperate climatic regime with relatively a well-balanced climate.

The urban settlements of the Kathmandu Valley are one of the oldest human settlements in Asia (Depuis 1962). The early development of the towns in the valley is believed to have taken place probably during the period CA 300–800 AD and the most of the prominent settlements appear to have enlarged and consolidated by the beginning of the thirteenth century (HMG et al. 1975). Currently there are five municipal towns, viz Bhaktapur, Kathmandu, Kirtipur, Lalitpur, and Madhyapurthimi, and over a dozen of market towns in the valley. Juxtaposing these five towns, the Kathmandu Valley is the largest urban agglomeration in Nepal.

The Kathmandu Valley is a legendary for its arts and culture and possesses seven protected monument zones, which are also the UNESCO World Heritage sites (ETG 2012). They are unique features of the valley's cities and towns that have been attracting tourists from across the World, as well as within the country (Fig. 18.4). The cultural and historic assets of the valley have however been threatened because of losing of their original traditional arts and culture, as well as are suffering from the deterioration of infrastructure, lack of basic urban services, traffic congestion, and intense pressure from population growth and commercial development. Further, the *guthis* of Nepal – one of the indigenous systems that traditionally played an important role in the conservation and perpetuation of cultural heritage – have been significantly weakened after the nationalization of *guthi* land in 1961.

Kathmandu represents the urban features of the Kathmandu Valley. It is the only metropolitan and capital city of Nepal and therefore receives the most attention of the central government. The share of the capital expenditure for municipal infrastructure by Kathmandu is highest, where the infrastructure need is greatest due to largest population size, though per capita spending in Kathmandu is less than that in sub-metropolitan cities and other municipalities. In 2010, per capita capital

Fig. 18.4 Cultural historic Kathmandu city

expenditure on infrastructure (physical and social) was US$6 in Kathmandu compared with US$6.3 in Biratnagar, US$7.9 in Birganj, US$9.2 in Lalitpur, US$6.8 in Pokhara, and US$11 in 53 municipalities (World Bank (2013)). The bulk of municipal infrastructure expenditure funded through project-based programs is allocated to municipal roads in Kathmandu. Solid waste management expenditure is mostly concentrated in Kathmandu. In 2008, solid waste accounted for 65 % of total capital expenditure for municipal infrastructure in Kathmandu, whereas it accounted for only 2 % in other municipalities.

Kathmandu has recorded a rapid population growth rate of over 4 % over the past three decades. Such a fast rate of growth is expected to continue until 2020, when Kathmandu alone will reach more than 1.5 million people. Migration is an important driver of urban transformation and is increasing over time in Kathmandu like other urban areas of Nepal. During the 1990s, migration contributed about 30 % to Nepal's total urban growth and as much as 40 % to urban growth in Kathmandu, which has the largest net inflow of migrants among urban areas (ADB 2010). The net inflow of migrants in the Kathmandu Valley accounts for 36 % of the valley's urban population (CBS 2012). More and more migrants are pulled to the Kathmandu Valley by economic opportunities. Employment opportunity has been the largest reason (25 %) for in migration to Kathmandu, followed by education, health and other reasons.

One of the consequences of rapid urbanization in Kathmandu is the rapid change in land use patterns (Fig. 18.5). Increase of built-up land is the highest at 8.2 % point, increased from 23.3 % in 2003 to 31.5 % in 2012, while agriculture land use declined by 7.9–44.7 % in 2012 from 52.6 % in 2003 (Shrestha 2014). Urban sprawl has spread to all directions, encroaching upon agricultural land. In 1991 both built up land and agriculture land accounted for 8.9 and 56.8 % respectively (Haack 2009).

The increased needs of the government infrastructure and functions in administration, health, education, banking, tourism, improvements in transport linkage both within and outside the valley and increase in government expenditure on

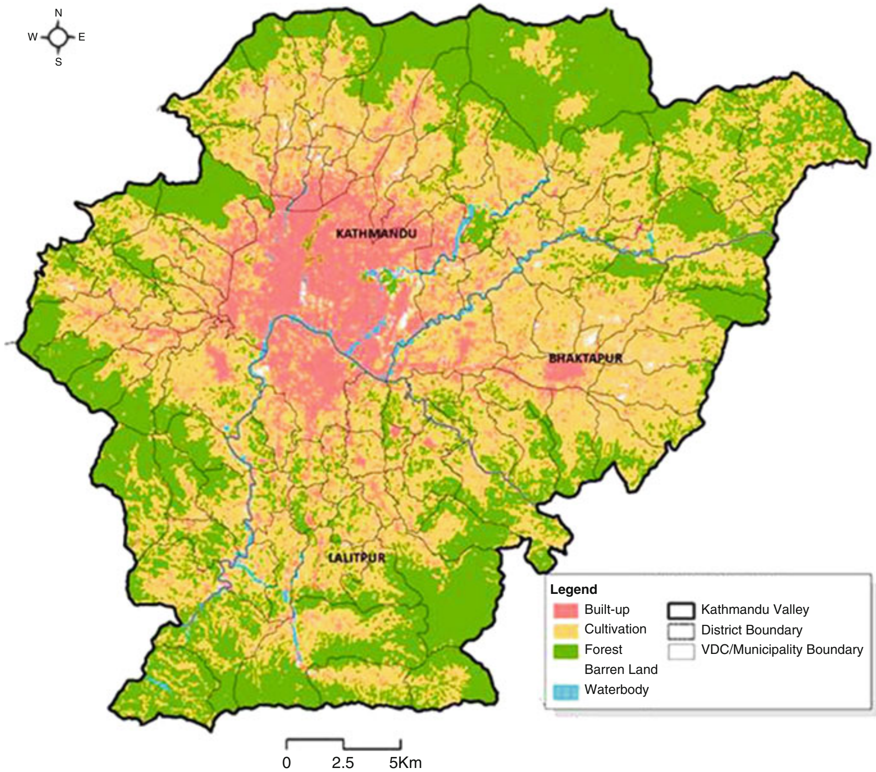

Fig. 18.5 Land use, Kathmandu (Valley), 2012

urban infrastructure development such as water pipelines, electricity, sewerage system, telephone and street network, land and housing, and a major economic hub in the country are driving factors of rapid growth of Kathmandu urban area (Thapa and Murayama 2010; Pradhan 2003). In addition, Kathmandu owns largest number of education institutions, private companies, standard hotels, international aid agencies.

The Kathmandu urban development pattern is environmentally unsustainable (Fig. 18.6). Unplanned urban development and poor enforcement of regulation have led to rapid and uncontrolled urban sprawl and loss of open space. They have also significantly increased vulnerability to disasters. Seismic hazard is very high in the Kathmandu Valley. Geologically, the Kathmandu Valley is as vulnerable as Haiti.[4] Many large structures such as temples and monasteries constructed of heavy rock, bricks, mud mortar, masonry, and timber, as well as individual houses having low

[4] Haiti experienced a devastating by earthquake at 7.0 Richter scale on January 13, 2010 that resulted in the loss of over 200,000 lives and left 500,000 people homeless (Bhattarai and Conway 2010).

Fig. 18.6 Urbanization of Kathmandu city

tensile strengths, would be destroyed even in a moderate earthquake (JICA and MOHA 2002). This would also have devastating effects on the most densely populated areas of the core Kathmandu, where buildings stand side by side on narrow alleys. Fire brigades and ambulances are unable to provide services, due to narrow streets limit.

Kathmandu has over past few decades witnessed a rapidly growing of squatter settlements and slums and faced challenges to their planning and management. Their number has increased from 24 in 1988 to 45 in 2008, occupying mainly the public land, shrine complexes and river banks which are ecologically sensitive and with deficient of basic facilities (Pradhan 2008). In Nepal, only the Kathmandu Valley's cities have some sewerage facilities, but the sewage treatment is still very poor and most wastewater flows untreated into all major rivers. Further, while bricks are the preferred material for construction for private and public buildings in Kathmandu, the primary impacts by the industry are air pollution resulting in human respiratory difficulties and decreased soil quality and crop productivity and the brick industry is essentially unregulated in location and environmental impact (Haack and Khatiwada 2007) (Fig. 18.7).

The Kathmandu Development Authority has been set up to facilitate functions pertaining to land use plan, development in urban land, construction works, maintenance of cultural heritage, protection and conservation of environment and natural resources of the Kathmandu valley including Kathmandu urban area. There is a plan of the urban feature vision for the Kathmandu Valley by 2020. This plan prepared by KVTDC (2000) has envisaged strategies for development of the Kathmandu Valley such as development initiatives in regional context, development nodes, efficient land use planning, conservation of agricultural areas, transportation based planning, accessibility to open space, settlement expansion with infrastructural facility and improving the carrying capacity of the valley.

Fig. 18.7 Narrow street, Kathmandu city

18.6.2 Pokhara

The Pokhara Valley encompasses Pokhara Sub-Metropolitan City (hereafter Pokhara), which is located 200 km west of Kathmandu. It is the second largest city of Nepal, as well as the headquarters of Kaski hill district and the Western Development Region. The average elevation of the surface of the Pokhara Valley rises from 700 masl to as high as 7500 masl over 30 km span towards the north. The Seti River flows through the middle of the city from north to south, cutting through many narrow and deep gorges where it has developed several layers of terraces and goes underground in many places. Pokhara receives an average annual precipitation of 3830 mm, the highest in Nepal. The surrounding hills, which together with two magnificent Himalayan peaks – Machhapuchhre and Annapurna from further north-west overlook the entire Pokhara Valley (Fig. 18.8). The Pokhara Valley is one of the most attractive valleys both in Nepal and World. The valley with panoramic scenes combining the Himalayan peaks and Phewa lake is unique that is unmatched with any parts of the World (Hagen 1971).

Historically, the Pokhara Valley had got influx by outsiders from within Nepal in the mid-eighteenth century. It also became a refugee center for the Tibetan refugees and followed by Muslim fugitives from Kashmir. Further, the town began to grow after the malaria eradication program of the late 1950s.

Pokhara is one of the fastest growing cities of Nepal. Since designated as a municipality in 1962, the growth of population of Pokhara has been very rapid. In 1956, the city had only 4000 inhabitants that increased to just over 5000 in 1961 and now the population reaches nearly 265,000. The population thus has increased by about 49 times over the past five decades. During the 1981–1991 decade, the average annual urban growth of Pokhara was 7.4 %, which was the highest among all 58 urban areas of Nepal. Pokhara became a sub-metropolis in 1995.

Fig. 18.8 Cityscape of Pokhara city

Migration of population to the city has been the main reason for the rapid growth. In 2001, the rural–urban migration constituted about 83 % of the total migration in the Kaski district, the majority of which in Pokhara city.

The economy of Pokhara city is predominantly supported by the service (tertiary) sector, sharing over two-fifths of the total employed population, followed by other sectors such as secondary sector (manufacturing – nearly two-fifths), and agriculture (below 8 %). The economy of Pokhara is based mainly on its thriving tourism, which is considered as the most potential sector for overall development of Pokhara. The city is gateway to the Annapurna Trekking Circuit, one of the best class trekking routes in the world. The contribution of tourism combining hotels and restaurants, light industries, trekking, pleasure and sightseeing, mountaineering, religious travel, river rafting, medical tourism and village and home stay to GDP is about 17 %. Pokhara now is being the most prosperous city, having the lowest level of poverty at 1.3 %, among all municipalities of Nepal. The city is well connected to the rest of the country through road network and air service.

Pokhara has economically competitive products such as tourism, carpets, and cut flowers in the international market. In terms of labor-based employment, lake-based fishery (having largest number of lakes in Nepal) has high potential for economic growth.

But the available infrastructure in Pokhara city is fairly poor to leverage economic growth and spatial integrated development. The urban government needs to be tuned to facilitate more income-generating opportunities such as tourism, cut flowers, and traditional handicrafts. Further, road and transport network links to production centers, fast track lines and/or expansion of current highways to Kathmandu, Narayanghat, and Butwal, electric ropeways to tourist spots in the mountains, an international airport, and opening of hot spring spas along the high mountain trekking areas could accelerate economic growth.

The land use of Pokhara city has been changed constantly along with urbanization over the past decades (Fig. 18.9). The built-up area makes up 54 % of the total municipal area, increased from 43 % in 2000 and 7.1 % in 1979 and is estimated to grow to almost three-fifths by 2021. While arable land and open fields have constantly been encroached by sprawled urban built-ups, greenery or forest coverage has nonetheless increased slightly. For instance, the agriculture land reduced considerably to 33 % from 34 % in 2000 and 76 % in 1979 where as the forestland increased now to 3.8 % from 2.2 % in 2000. There is no urban land use zoning laws in Nepal and as a consequence, a major challenge facing by Pokhara like other cities is how to manage haphazard urban growth. The only regulation and guideline available in the Pokhara city is the building by-laws.

With increasing urbanisation and tourism activities, haphazard sprawl of urban built-ups has taken place across the valley, causing pollutions in the lakes and rivers as well as on the land. Further, the crucial problem the city now facing is the lacking of improved infrastructure and services, including narrow and ruined roads, haphazard dumping of wastes, deficient of water and electricity supply, poor management of public transports, tourism information and communication, and lack of land use and periodic plans. Water hyacinth, for instance, is a recent phenomenon of aquatic plant being spread across the Phewa Lake, which is due to nutrients formed by the organic wastes. The lake has been encroached upon by locals and invaded by weeds, making it extremely vulnerable and is now in real danger of extinction (Pradhan 2014). The downstream part of the Phewa Lake and the Seti River is being polluted by dumping plastics, sewer and other wastes.

The slum population of Pokhara city accounted for 3.6 %, which is far below the national urban slum population of 7.1 % (Lumanti 2010). The slum areas are characterised by deficiency in access to piped drinking water, education, and living in vulnerable houses with sharing toilets (Gurung 2008). In mid-2013, however Pokhara was declared as the cleanest city of Nepal.[5] Further, the Pokhara Valley experiences flash floods occasionally. In 2012, massive flash floods occurred in the Seti River due to broke down of the blockage of the river course by the avalanches in its upstream. According to the local inhabitants, a similar disaster was occurred

[5] Pokhara was declared as the country's 'cleanest city' by the Ministry of Urban Development and the Solid Waste Management Technical Centre (SWMTC) on the World Environment Day (Wed 5 Jun, 2013, The Kathmandu Post; http://www.urbangateway.org/content/news/pokhara-countrys-cleanest-city)

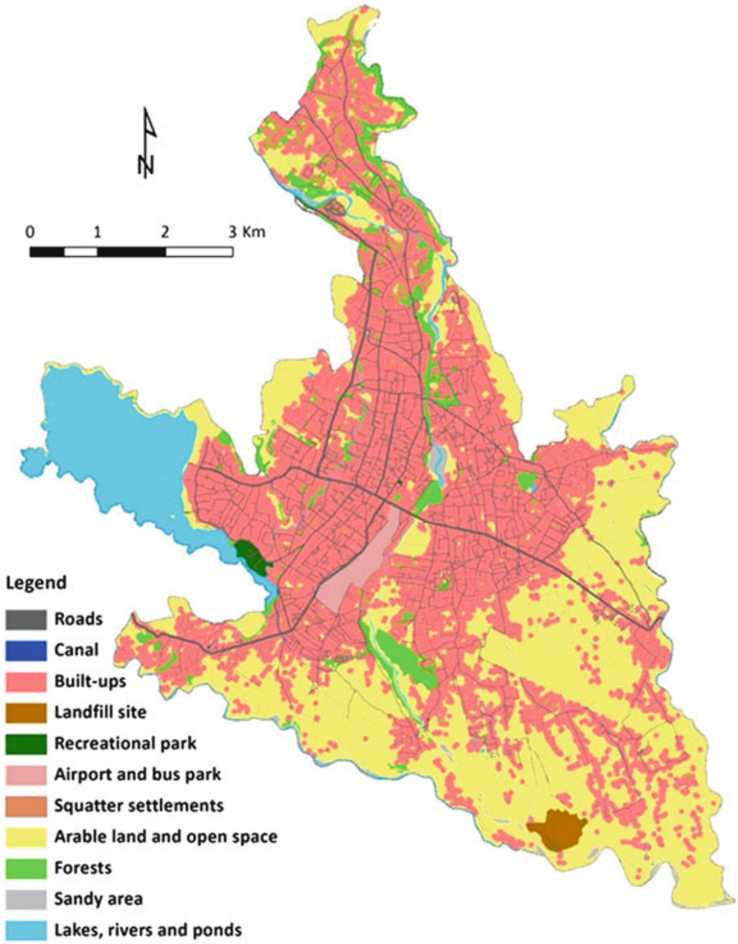

Fig. 18.9 Land use, Pokhara 2010

in 1959.[6] In November 2013, several sinkholes happen to be developed in the northern part of the valley where the area has limestone calcium or carbonate rocks in the underneath surface, creating uncertainty for further development of the area.

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[6] It is argued that, the melting of snow up in the Himalaya – the Annapurna, due to the global warming caused to burst its bank sending the wall of water cascading down the water forced down to the Seti River in Pokhara Valley killing at least 13 people and missing over 50 persons on May 6 2012. The relatively high casualty rate and swept away the Kharapani Bazaar on the bank of the Sardi Khola, one of the tributaries of the Seti River was probably due to settlements and sand mining activity by people who didn't expect floods during the dry season (The Himalayan Times, May 13, 2013). On July 12 2012, 30 people were rescued out of flood at Ramghat downstream of the Seti River in Pokhara, caused by incessant rainfall inundated their houses.

A number of development plans have been made for Pokhara city, but most of them have not been implemented. For instance, the first development plan for Pokhara was prepared in 1965 and based on this, the detailed physical land use plan with a 20-years horizon was proposed in 1967. The plan identified four milestones in the development of Pokhara, such as a nodal point at the crossing of two major travelling routes (north–south and east–west), a center of pension camps for the retired Gurkhas of India and British that led to a spin-off in the commercial sector; the second most visited town in Nepal by tourists, and a regional center of administrative, health, education services. In addition, the fifth milestone in its development would be the opening of an international airport. The land use concept plan as a policy paper for Pokhara city prepared in 2000 that was to provide framework for the future development of Pokhara. The plan suggested providing necessary infrastructure, services, amenities and some basic qualities in order to safeguard the quality of the city and provided direction to the municipality to further action, decisions, funding and taxation. The tourism policy for Pokhara, though formulated over 15 years ago, appears to be still important (Pagdin 1995), as it suggested that the most appropriate objective of tourism industry would be to focus on attracting more quality tourists (i.e. hotel-based rather than backpacker) and this would probably best be achieved by improving tourism related infrastructure such as quality of transport to Pokhara, upgrading accommodation both within Pokhara and in the surrounding hills, and increasing the number of tourist facilities. Likewise, the Master Plan 2002 aimed to develop the lakes as tourist spots and as important wetlands has not yet been implemented. Recently, two plan documents have been prepared such as the Pokhara Tourism Master Plan 2013 and the Pokhara disaster plan 2013. The tourism master plan has been prepared to develop tourism for the 5 year duration (2013–17). The disaster plan has identified vulnerable buildings based on their structure, open spaces with different levels to be used during emergency, guidelines for mitigation and preparedness, immediate measures, rehabilitation, and potential hazard zones of natural depression/sunken area.

18.6.3 Biratnagar

Biratnagar lying in the far-east along the Nepal-India border is the third largest city of Nepal.

Biratnagar was recognized as headquarters town of Morang district in 1914 that was moved from Rangeli. It was designated as municipality in 1953 and Sub-Metropolitan City in 1995. The average elevation of the municipality is 70 masl. The sub-tropical climate with relatively more humidity prevails in Biratnagar.

Previously, Biratnagar was known as industrial city where relatively larger number of manufacturing industries of Nepal was located and now most of the manufacturing industries are shifted along the Biratnagar-Duhabi-Itahari road corridor.

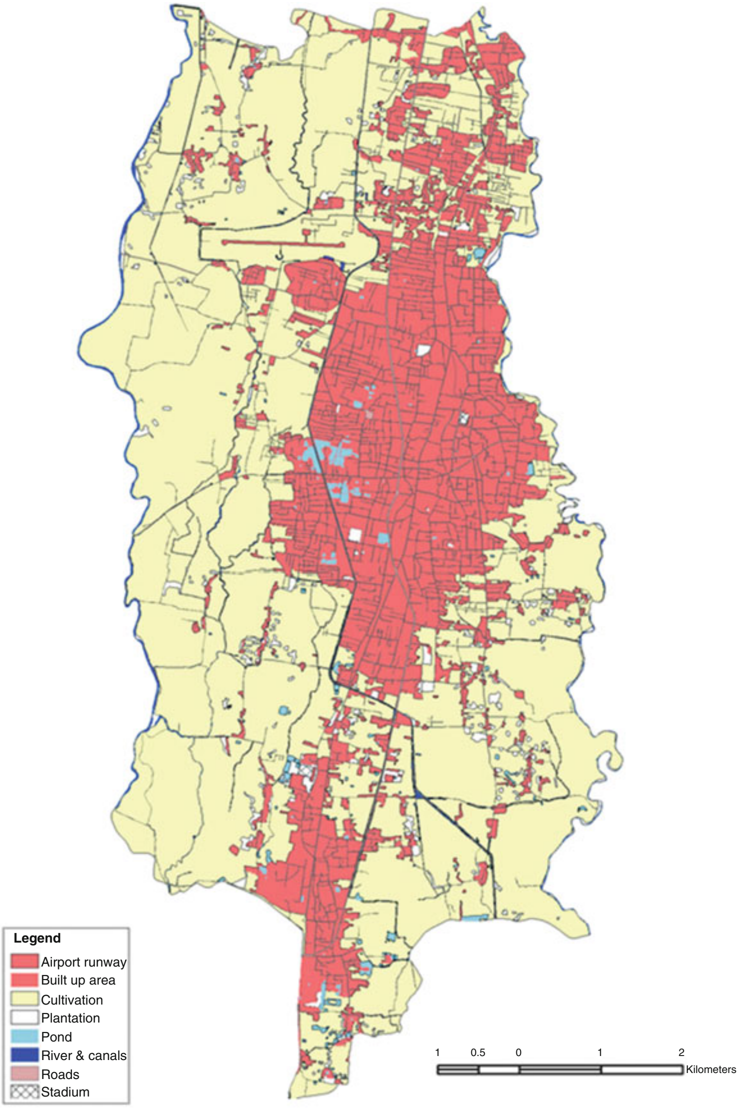

Fig. 18.10 Land use, Biratnagar, 2009

In 1952, the population of Biratnagar city was 8060 and grew by more than fourfolds, i.e. 35,355 in 1961. By 1981 the population reached to 93,544 and until 2001 with the population of 166,674, it maintained as the second largest city in Nepal. However, the urban growth rate is comparably less compared to Kathmandu and Pokhara. Mostly the cultivated land and forestland have been changed into the urban land (Fig. 18.10). In 1976, urban area had occupied about 5 %, increased to 38 % in 2009, mostly encroaching upon arable land. It is estimated that the built up will cover over 48 % by 2019, while agriculture land will decline to 46 % (Rimal 2011). The agriculture land decreased from 79 % in 1976 to 56 % in 2009. The forestland also diminished from 5.8 % to about 1 % during the same duration of the years. So, the land use changes would have impacts on the city environmental and landscape including the quality of water, land and air, ecosystem, and climate system.

Biratnagar encompasses extensive surrounding hinterland region. Industry and trade provide two important linkage functions to Biratnagar. The manufacturing sector of Biratnagar region alone contributed about 21 % of national GDP. It acts market linkage function as goods trading points between the hills and the Tarai. Biratnagar is Nepal's principal city for international trade, including India and foreign countries by using the Indian railway lines.

Top three potential commodities for unleashing economic growth of Biratnagar urban area are herbs and spices, garments and hand loom, and vegetables. Cardamom, tea, and ginger are among the important exportable herbs and spices. Jute, sugarcane, dairy, and cereals (rice) are other important products for income generation in the area.

Though Biratnagar has relatively better infrastructure for development than other urban centers of the eastern region, it requires prioritizing infrastructure investment to jump-start growth on road and transport networks, electricity, labor-based industrial activities, market expansion and on top of them is to open access to the Bangladesh's Banglabandh seaport via the "Chicken's Neck" of India. This transit route would have about 80 km, far shorter than the current transit route of over 700 km from Birganj to India's Calcutta port. This is the shortest transit route for cost effectiveness and competitiveness of the import and export items. Further, the dry port infrastructure in Biratnagar for loading and offloading merchandise commodities appears to be in most urgent need to unleash economic growth.

18.7 Discussion: Key Emerging Issues and Challenges

The followings key issues and challenges may be derived for the urban environment management and development of the urban system of Nepal.

- Urban economy is a vital sector for overall development and strengthening national economy of Nepal. Urban sector has contributed to about 62 % of total GDP, but this sector is being given least priority in the current national budget, receiving merely below 1 % of the national budget (World Bank 2013).
- Inadequate urban infrastructure is a major constraint to leveraging the comparative advantages of urban areas in Nepal. Overall, the level of infrastructure available in the urban areas is fairly poor, below 50 % (ADB 2010). The Global Competitiveness Index report ranked Nepal as the country with the least competitive infrastructure among the 139 countries (World Economic Forum 2010).

- Since the early 1990s, the planning focused on promoting urban development as a means of boosting rural economies, but they remained with marginal impact. Until now, the urban government's efforts have not matched expectations because of: (i) investment is required everywhere but government resources are very limited; (ii) thin spread of limited resources has resulted in minimal growth despite several decades of government programs; (iii) strategic framework for prioritizing investments is hardly available for urban sector development, which is yet needed to optimize investment outcomes and achieve growth impact efficiently.
- The roles and responsibilities of two ministries – the Ministry of Urban Development and the Ministry of Federal Affairs and Local Development seem quite conflicting and confusing in regard to planning and managing urban areas in Nepal. While the former assists the municipalities and other towns in developing and implementing physical planning, urban development, etc., the latter deals with defining municipalities and resources allocation for governance purpose. Thus, defining urban areas in terms of population threshold of 10,000 for the hills and mountains and 20,000 for the Tarai basically for administrative purpose has ignored the economic vitality and viability of the towns. This practice is also responsible for denying several small towns though they have roles in fostering secondary and tertiary economic activities in real terms and thus ignoring their role in urban system dynamic. On the other hand, many municipalities do not have any plans like land use plan.

18.8 Conclusion

It is obvious that urbanization offers significant opportunities to reduce poverty and to promote sustainable development in a country like Nepal which is still at an incipient level of urbanization. Therefore, urban policy interventions should be directed at providing a minimum level of municipal services across urban areas, ensuring sustainable and inclusive growth and development of urban areas. In saying so, some of the measures for integrated and balance urban development and environmental conservation can be suggested. First, managing urban areas has always been an important issue. The vital idea that development of urban areas as a necessary condition for socioeconomic transformation in rural hinterland areas has never been conceived in Nepal's urban sector policies. So, shifting in the existing urban sector strategy is essential in the changed political context. A region-based urban development approach is more appropriate than simple urban development within the strict urban jurisdiction alone. Here, concern should be with strengthening the functions of urban areas to be directed to facilitate urban–rural economic links and long-term transformation of the country's traditional economic structure. Secondly, investment in urban infrastructure should be increased far more than the current level and priority should be given on areas according to the economic potentialities (in competitive and comparative terms) of the urban areas and their regions. Also investment in development areas should be more focused according to strategic priorities rather than randomly picking up investment areas based on political interests. Collaborative governance, smart town approach, public private partnership etc. should be taken for increasing investment in urban productive infrastructure. Thirdly, the number of small and medium sized urban centers should be increased for a balance urban system. In the Hills and Mountains, by virtue of the spatial proximity location, still the small centers have significant roles in facilitating urban services to surrounding widely dispersed population clusters. In so doing, municipality should be redefined to include smaller towns having population 2000–5000 which are spreading widely across the country so that their potential urban functions such as marketing activities, secondary and tertiary works can be recognized and reinforced to offer key services to surrounding dispersed population clusters. Such compact towns should be given institutional status, so that they can proliferate with organized urban form, and be developed as more livable places. Fourthly, the fundamental problem now the urban areas facing in Nepal is the lack of a modest urban land use zonation policy. Formulation of urban land use policies and plans is a must and their implementation has to be made. Lastly, urban planning, especially land-use planning is a tool to develop an area in a proper way and therefore, urban areas need clear rules and regulations to guide their development. In Nepal, the Local Self Governance Act and its regulations provide precise guidance for urban planning, but the act is virtually dysfunctional. Yet further to establish proper way for planned urban development, the Government should have to carefully examine existing laws and regulations and make them coherent and implementable.

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Chapter 19
Fighting Floods for Survival: Experiences of Suffering People in Bangladesh

Tulshi Kumar Das

Abstract Floods are more recurrent than any other disasters that affect the people of Bangladesh. Global warming and resultant climate change has made the situation worse, especially for Bangladesh as the vast coastal areas stand highly vulnerable to floods and other natural disasters due to steady rise of sea level. Moreover, rainwater coming from the upstream on the other side of Bangladesh-India boarder inundates the low lying lands in the downstream of Bangladesh during the time of monsoon. The current study is conducted in greater Sylhet region of Bangladesh which is known as flood prone areas since it gets affected through flooding almost every year. The sufferings of the people living in the four districts of greater Sylhet, namely Sunamganj, Moulvibazar, Hobiganj and Sylhet seem to be never ending. The study aims to investigate multidimensional fighting strategies of flood affected people to cope with the situation of flooding for the sake of survival. It is a qualitative interpretation of 40 suffering household heads who have been selected from 4 districts; 10 from each district by following simple random sampling procedure. Of 40 respondents, only 4 are found female household heads, and the rest are males. The findings of the study show that sufferings of the affected people are massive, but they still do not give up, never lose hope; rather they are committed to bounce back as they know very well that is how they will have to survive.

Keywords Adversity • Coping and resiliency • Disaster • Fighting-prone • Flooding • Migration

19.1 Introduction

Bangladesh is a country of multiple natural disasters. It is frequently affected by flooding, tidal surge, tropical cyclone, tornado, incessant rainfall, river bank erosion, drought, thunderstorms etc. (Alam 2005; Ali et al. 2013), though flooding is considered most threatening as it occurs massively year after year (Paul and

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Routray 2010), sometimes more than once in a single year, killing innumerable people, livestock, poultry and devastating as well as damaging property, standing crops, life and livelihoods, often causing people homeless and destitute (Few 2003; Paul 1997; Sultana and Rayhan 2012). Floods in Bangladesh seem to be unavoidable because of its very geographic position, laying within the catchment areas of three big rivers namely the Ganges, Brahmaputra and Meghna that flow through Bangladesh into the Bay of Bengal. The country is mostly covered with low-lying river delta, having more than 230 rivers and tributaries and also located between the foothills of the Himalayas and the Bay of Bengal that makes it highly vulnerable to frequent flooding (Sultana and Rayhan 2012). River delta causes the entire land fertile, but at the same time around 60 % of the surface of the country's earth remains low-lying, which is even less than 6 m above the mean sea level (GOB 1992; Paul and Routray 2010; Sultana and Rayhan 2012; USAID 1988). In general, about 20.5 % of the country (3.03 million hectares) goes under water every year because of floods (Chowdhury 2000; Mirza et al. 2001), but high-magnitude floods inundate up to 70 % of the country, causing widespread damage (Mirza 2002). The intensity of flood varies from year to year as heavy rainfall during the time of monsoon along with rainwater coming from the upstream Himalayas spillovers most of the rivers in Bangladesh that frequently deteriorates the situation of flooding across the country. Sometimes a flood of a small-magnitude affects only a local area of the country, making only the inhabitants of that locality suffer. Flooding with a greater intensity strikes almost the entire country which brings about untold misery, sufferings, helplessness and uncertainties for people of all socioeconomic categories, which also cause huge loss of lives of human beings and livestock as well as devastation of property (Paul and Routray 2010; Paul 1984, 1997; Rasid 1993). Floods occurred in 1988, 1998 and 2004 which were massive and heavily destructive had engulfed the major floodplains (60 %) of the country (Brouwer et al. 2007). It is to be noted that flooding in Bangladesh has never been a new natural disaster (Khandker 2007); rather it has gradually become a common and more frequent natural catastrophe these days on the face of rapid climatic changes. Not only heavy rainfall, even when the rainfall is recorded average larger part of low-lying areas of the country remains flooded for a considerable amount of time as it happened in 2005. It is thus an every year affair which people confront, adapt and strive as they have no escape from it (Sultana and Rayhan 2012).

The effects of flooding are always multidimensional and multifarious in Bangladesh. It has been anticipated that the floods occurred in 1974 had a disastrous impact as that created severe famine which had left 30,000 people dead (GOB 2006). Around 1800 people died and another 30 million people were affected in the flood occurred in 1987 which inundated 40 % of the country. This flood caused the loss of 0.8 million tons of rice as the paddy was extensively damaged. But the flood in 1988 was even more severe compared to 1987, which left 2300 people dead and 45 million people affected; and 62 % of the country went under water. Bangladesh witnessed its worst flood in 1998 after the independence when 68 % (more than two-thirds) of its land was inundated for about 3 months (Khandker 2007), killing about 2380 people and devastating 1.56 million hectares of crops; which also destroyed around 900,000 houses across the country. Two-thirds of the country was completely inundated because of overwhelming monsoon flood that took place in 2004, killing 726 people and affecting 35.9 million people. This flood made millions of people homeless and hundreds of thousand people suffered from waterborne diseases. The flood in 2005 inundated around 12 % of the country's total area (Sultana and Rayhan 2012). In 2009, Bangladesh experienced another dangerous flood that killed innumerable people and damaged all kinds of property badly during the months of May and June. Food production went down considerably as rice and wheat crops were enormously spoiled. In May 2009, a massive tropical cyclone *aila*, as it was named, hit Bangladesh for the first time, resulting in heavy rainfall that caused massive flooding across southwest coast of the country. The immediate impact of cyclone *aila* left 190 people dead and around 7100 injured, which also affected over 3.9 million people. Almost 100,000 livestock died and nearly 350,000 acres of crop land were damaged. Incessant rainfall resulted from *aila* further caused landslide at different places in the country, and tidal surge of *aila* spoiled agricultural land as it was flooded with saline water making entry into it from the sea. The overall situation deteriorated furthermore because of shortage of food availability and lack of pure drinking water. The food price, especially rice, became doubled immediately after *aila* during the time of summer in 2009 (UN 2010). Bangladesh has experienced floods with different magnitudes on regular basis in 1971, 1974, 1978, 1984, 1986, 1987, 1988, 1989, 1991, 1993, 1995, 1996, 1997, 1998, 1999, 2000, 2004, 2007 and 2009 after its independence in 1971 (Kamrujjaman and Das 2011). Since flooding is a frequent happening in Bangladesh, thus people do not seem to be scared of it rather prefer to face with courage and determination.

This study was conducted in greater Sylhet that included Sunamganj, Moulvibazar, Hobiganj and Sylhet districts in order to understand the nature of fighting of flood affected people living in this eastern part of Bangladesh. Sylhet is widely known as low-lying area, very much prone to frequent flash flooding. The region is low-lying as there are many *haors* (wetland ecosystem) located in this part of the country. It is almost every year greater Sylhet suffers enormously from flash flooding during the time of monsoon. The local dialect *haor* is often used to mean low-lying area of Sylhet which collects surface runoff water through rivers and *khals* (canals) that makes most of the *haors* expanded waterbodies in monsoon, though these *haors* become dried up in post-monsoon period. Over 5 million people live in six north-eastern districts of Bangladesh including 4 districts of greater Sylhet where countless number of *haors* is found located. These people are socio-economically poor, mostly dependent on agriculture, many of whom are simply agricultural workers; who are also forced to change their occupation from agriculture to fishing because of monsoon floods that cause agricultural lands inundated for an indefinite time, generally from 3 to 6 months every year. Around 70 % of the inhabitants of *haor* areas are landless and relatively asset poor who lose their livelihoods due to flooding that discontinues all land-based agricultural activities (Alam et al. 2008; Pulla and Das 2015). People are only able to grow mono crop that is called *boro*—a rice variety during the time of winter from January to April; and most of its land remain under water from July to November when inundated lands transform into floodplains and the people resort to fishing for livelihoods (Kazal et al. 2010; Pulla and Das 2015).

Floods may be described as perennial in the region of Sylhet, and it is believed that there is no solution to it. Therefore, people living in this flood prone area have become habituated with the situation of flooding as they face it, fight and adapt it and sometimes feel forced to migrate to a safe shelter for survival, but again come back to the origin, start life afresh and wait for the same disaster next year. It is strongly entrenched culture which goes on from one generation to another and that is how the new generation internalizes the way of life of older generation living in the *haor* areas of greater Sylhet. There is no doubt that sufferings of the flood affected people are untold and unexplainable, but it is noteworthy that they do not give up during disaster rather adopt different strategies to reduce the crises (Pulla and Das 2015). The suffering people are creative and know it better as they undertake a number of preventive and mitigative steps to handle the situation of flooding as per the demands of overall circumstances (Corbett 1988; Paul and Routray 2010). This study delineates as to how the flood affected people of Sylhet region fight flooding that occurs each year and destroys the life system of the inhabitants who always regain their strength and energy to resettle themselves for a new life after the disaster.

19.2 Conceptual Framework

This study is based on the experiences of the people who fight the situation of flooding that they face and sustain every year amid terrible uncertainties. Fighting floods mean the way flood affected people cope with the situation and make themselves resilient, and also build up new hopes and dreams on the face of frequent flash flooding in the region of greater Sylhet. So, fighting floods are essentially related to coping strategies and resiliency of affected inhabitants who courageously trigger the struggle for their own survival. Coping and resiliency help people fight any disaster that they confront.

Coping and resilience are interrelated and interdependent. Coping capacity of the people push them to adapt to an adverse situation, or people gradually grow coping capacity to withstand adversity. Resiliency makes the people resilient who do not give up in difficult times, especially during and after disaster, rather they reach out to others for support (Fetsch et al. 2013). Coping may help an individual to find out a positive meaning of a difficult situation that can benefit the person, his or her spouse and the entire family (Nel and Righarts 2008). To be precise, coping may be described as to cope with, which means coping with disaster in the context of the current study. Coping strategies are the approaches people employ to deal with a crisis successfully (Davis 1996). It is in fact adaptive strategies to face adverse circumstances. On the other hand, resilience encourages the people to be able to interact with their environment which helps them promote their own wellbeing as well as protect them from irresistible influence of myriad risk factors (Zautra et al. 2010). Resilience assists a person transform an extreme challenge into an opportunity which helps achieve better outcomes even in the face of loss (Tedeschi and Calhoun 1995, 2004; Linley and Joseph 2004). People gradually build up resilience through hardship and struggle in their day-to-day life, generally not achieved overnight. The process of resilience could be developed, widened and deepened (Lewis et al. 2011) by those who constantly live in vulnerability; and resilience may also be context-specifically grown (Pulla et al. 2013, pp. 12–13). Resilience is a kind of fighting capability of an individual, group and community in an adverse situation which is expected to transmit from generation to generation. It is likely to be absorbed and implanted into the cognitive domain of the people (Pulla and Das 2015). Resilient people fight back to overcome a disaster which brings them new hopes and dreams. It is thus extremely important to generate resilience among the people who frequently suffer from multiple forms of hazards and crises. Resilience has been explained as rooted within 'our beliefs and values, in our character, experiences, values and genes (and influenced by and influencing of) our *habits of mind*—habits we can cultivate and change' (Zolli and Healy 2012, p. 14.). It is true that resilience often remains dormant in a normal situation, but comes up when needed, especially during the time of emergency. Scholars (Luthar and Cicchetti 2000; Pulla 2013) have argued that resilience grows as the people come across with the situations of adversity, risks and negative life circumstances that are likely to affect them very badly.

The flood affected people fight flooding every year through the process of coping mechanism as well as resilience for mere survival. It is not possible for them to fight recurrent flooding without developing coping and resilience into their cognitive domain, and thus fighting floods are indispensably connected with coping strategies adopted and resiliency developed by the flood affected people. Coping is something to learn, but resiliency is something to acquire in a negative circumstance (Masten and Coatsworth 1998; Revich and Shatte 2002; Schneider 2001; Abramson et al. 1978; Siegel 1999). Both coping and resilience of the people constitute 'fighting' that is raised in the situations of floods, which they feel forced to do for survival.

19.3 Objectives of the Study

The general objective of the study is to interpret, explain and understand the nature of fighting that the flood affected people lodge during flooding for their survival. The specific objectives of the study are:

(a) To understand coping strategies adopted by the flood affected people;
(b) To investigate the ways flood affected people build up resilience to fight flooding;

(c) To explore and analyze other resources used by the flood affected people to fight against all barriers during perennial floods in the region.

19.4 Methodology

The study was undertaken in Sunamganj, Moulvibazar, Hobiganj and Sylhet districts of greater Sylhet region. Four villages, one from each district, that were attached to *haors* had been purposively selected for the study. Ten households from each village were selected by following simple random sampling procedure that made up the total number of households as 40. All the selected villages experienced severe flooding almost every year. The selected 40 households have been suffering from flooding not only once a year, sometimes 2 or 3 times a year. Household heads were interviewed using semi-structure interviewing method in order to collect data relating to their experiences of fighting during the time of each flooding. Of 40 household heads, 04 were females who also fully cooperated with the data collectors by sharing their experiences of suffering and fighting during floods. Four focus group discussions (FGD), one FGD in each village, comprising key informants like school teachers, religious personalities, local politicians, representatives of local government etc. were held to cross check the data collected from semi-structure interviewing. Both the data received from interviewing as well as FGD have substantiated each other while explaining the experiences of overall fighting of flood affected respondents. The people who live in the villages attached to *haors* are socioeconomically marginalized, may be described as destitute, most of whom are almost landless. So the respondents of the study are more or less of same socioeconomic background. Eight data collectors were recruited, all of whom were graduate students of social work, economics and statistics department of Shahjalal University of Science & Technology. The data collectors were properly trained up considering qualitative nature of the study and also strictly supervised during the time of interviewing by the author himself. Informed consent was obtained orally from each respondent; and the respondents voluntarily agreed to be interviewed without demanding any compensation. The narratives presented in the study have been described by the respondents, each of whom has been assigned a pseudonym. Apart from primary data, secondary data have also been collected from different secondary sources to support the arguments in favor of the experiences of suffering people who fight hard to overcome the situation of flooding in Sylhet region.

19.5 Findings of the Study

Findings have been presented here as the narratives of the respondents shared with the research investigators in relation to their struggle to tackle the situations of flooding. The flood affected people literally combat frequent flash flooding during monsoon in the forms of developing coping strategies and building up resilience amongst them to overcome the crisis of flooding, and also to restart the life with new hopes and dreams. Whatever activities the affected people adopt to face the challenges that crop up due to monsoon flooding are all the parts of people's fighting to survive in the midst of destruction and devastation. Taking the main theme of the study into consideration different sub-themes encompassing essential elements of fighting floods have been developed, which have also been narrated with quotations of the suffering people.

19.6 Developing Coping Strategies to Fight Flooding

The people who live in *haor* areas in four districts of greater Sylhet have become quite accustomed to flooding. They seem to be almost sure about yearly monsoon flooding, and thus prepare themselves to confront it before the monsoon starts. The only thing that worries them is that the magnitude of flood that may hit the inhabitants in a particular monsoon. Still, instead of losing confidence, most of the respondents are found strong-minded to face the disaster of flooding of any intensity as they have no alternative. The first step most of them adopt just before the monsoon is to raise the platform of their house and placing different materials like muddy soil, brick, sandbag, branches of trees, wooden materials etc. around the house to save it from flooding. It is an indigenous coping strategy which is followed by many of the *haor* people before monsoon flooding. Thirty two respondents out of 40 told that they had always raised their homestead before the monsoon. They also often shift their occupation from agriculture to fishing for earning livelihood as agriculture activities discontinue because of inundation that keeps agricultural land submerged. Khalil (42), an inhabitant of a village under Sunamganj district describes,

> We are poor and don't have any cultivable land of our own. We have a small house on a piece of land which I bought 11 years back. My family consists of six members. Me and two of my sons are agricultural workers, grow crop in other's land in sharecropping system. We can grow crop once a year, rest of the time the land remains under water because of monsoon flooding. It is an every year affair. During the time of flooding we involve ourselves in fishing for earning livelihoods. Most of the inhabitants in this village are agricultural workers or crop farmers for 5 to 6 months in a year and fisherman for rest of the time during flooding. Floods of big magnitude often destroy our house. We, almost all the villagers, try hard to save the house from monsoon flooding by raising the platform of homestead and by placing barriers around it every year before the monsoon. I lost my house two times during flood, and I had to migrate along with my family members to a relative's house in a nearby village and stayed there for 5 long months as flood water did not recede.

> Afterwards, I with my family members came back here and built a new house for which I borrowed money from an NGO, and also from my relatives. We have to tackle the situation of flooding for our survival.

Many of the respondents suddenly lose their earning activities as almost the entire village goes under water due to monsoon flooding that inevitably results in unemployment, which also causes shortage of food for flood affected people. But they do not succumb to this situation; rather explore new opportunity for earning livelihood. Sometimes they curtail the number of meals a day and buy cheap food items or depend on food relief generally offered either by the government or NGOs (non-government organizations) till a new work is managed. In many cases (28 respondents out of 40), people store different food items in advance for emergency like flooding, so that they do not starve in difficult times. Khaleque (55), an inhabitant of a village under Moulvibazar district shares,

> We live near *haors* which is low-lying and naturally prone to flooding in rainy season. Nobody can help it. Everybody living here knows that he will have to live with flooding as the area goes under water each year. We are all low-income people and cannot migrate to a safer place. Thus, we have learnt to live with flood water with all risks and hazards. If the flood water stays for a longer time then it becomes difficult to run the family because of lack of employment. Fishing is the only earning source at the time of flood which does not ensure sufficient and regular earning. Then we generally buy cheap food and feel forced to skip taking food 3 times a day; instead we sometimes take one meal or at best two meals a day. Government and/or NGOs provide us with food relief at times that helps us survive in a difficult situation. We always store rice, *chira-muri* (fried and crispy rice) etc well ahead of flooding so that we can survive at least for some days in the time of flooding before getting an earning. But uncertainty crops up if the flood water does not recede quickly.

Although the villagers face flooding with courage and confidence, they remain cautious against flooding of high magnitude and recurrent happening of flood disaster. They generally do not want to leave their house during flooding, but if the situation of flood deteriorates that destroys their house or that poses a serious threat to their lives, then they immediately migrate to a safer place, mostly to a shelter house (schools, embankment or at the premises of government office) or a relative's house or a nearby city/town in a slum with all of their belongings. Sometimes in an emergency situation they are often rescued from their drowning house by NGO workers or law enforcing agency assigned to rescue the people and taken to a nearby shelter. They sell livestock, poultry, and some other belongings to meet up the urgent needs; sometimes they need to mortgage or sell their small piece of land and also borrow money from relatives or some NGOs or a traditional money lender unless a source of income is found. Aziz (48) from a village under Hobiganj district opines,

> A flood of high intensity destroys everything including our house and poses a serious threat to our lives that forces us to pack up our possessions and leave home for a safer place, though we stay at home as long as our house remains intact. I along with my family members had to move to a shelter as the flood water in 2007 just submerged my house. We and majority of the villagers were rescued to different shelters because of severe threat of devastating flooding. I had a small piece of cultivable land which I had to sell after the flood water receded in order to make my family members including two of my small children

> survive. I sold everything like one cow and two goats; and I had to borrow money from an NGO to meet up my family's urgent needs. I have now overcome that situation of uncertainties by the grace of *Allah*. We know that is how the people of *hoar* area will have to survive.

It is not only the platform of the house made higher or created blockade around the house to save it from flooding, the inhabitants of different villages in greater Sylhet region also make efforts to elevate the bed of the house with bricks, and sometimes the legs of the bed are tied with iron rod or strong wooden pillar so that the house does not get washed away with flood water. They do it particularly to save the lives of children as well as others. Hanif (52), a villager of Sylhet district tells,

> Our aim is to save the life first during flooding. We take different steps to elevate the platform of house, and also the bed inside the house to prevent flood water. Most of the houses in the village are made of clay or dried paddy plants and bamboo with straw or thatch roof or corrugated iron-sheet rooftop which is considerably vulnerable to flooding. Bed inside the house is raised with bricks and tied with iron rod or wooden pillar before flooding so that the bed does not sink in flood water easily. We do it mostly to save the life of the children or to prevent sudden flooding from taking lives.

Migration from the village to a safer shelter before or during flooding is almost common in all the villages in the region. But it does not mean that each family before or during flood always migrates from their village; rather they explore the situation first and also take their previous experience into consideration and then decide. It is noteworthy that decision of migration is generally taken as the last resort, if flooding is perceived as life threatening. Thus, migration mostly takes place during the time of flooding. There is hardly any family found which never migrated. But the inhabitants try their level best to live with flooding. This is also mentionable that some families feel compelled to migrate in each flooding, and some families somehow manage to stay back as they are comparatively less affected. Siraj (62), an inhabitant of a village under Sunamganj district explains,

> We migrate mostly to a nearby city, live either in a slum or in relative's house whenever flooding poses dangerous threat to our lives. It is a common practice among the villagers, though they do not intend to migrate but feel forced if the situation becomes severely threatening. I lost my house in flood water 4 times and had to migrate to Sunamganj city where my family members and I lived with my relatives, once for 6 months and then, later on, from 2 to 4 months in each flooding. We migrated on compulsion, but came back to our house in this village as soon as the flood water retreated. Most of the families try to stick to the situation of flooding with all willpower amid untold misery and suffering. We have now become used to.

Majority of the villagers sell livestock and poultry prior to flooding since they generally die during flooding. It is in fact a source of income for the *haor* people, and thus most of the families raise livestock and poultry to sell them in order to handle difficult situation created due to flooding. Some families take their livestock, poultry and other assets along with them while going to a shelter, but those who are unable to sell livestock and poultry or not allowed to take them to the shelter, they often lose them as flooding cause them die. Moreover, the villagers also try to take utensils, furniture, bedding etc. with them while moving to a shelter or relative's house, and sometimes they make a high dais with bamboo inside the house upon which they keep bedding, utensils and some other assets to prevent flood water from washing them away. This step is usually undertaken when a family does not move away despite facing the devastation of flooding. Parul (40), a female of a village under Hobiganj district, shares,

> We raise livestock and poultry to sell them before flooding so that we can earn some money which helps us run the family in the time of flooding when there is no work or a new work is yet to be managed. Many of the families in our village do it to avoid starvation during and after flooding. We know that rearing livestock and poultry literally helps the family members, especially children, survive in a tough time of flooding. Sometimes livestock and poultry die because of abrupt flooding which causes additional suffering for us. Some of the families take livestock and poultry along with them to a shelter before flooding. We often make a high dais inside the house to keep our utensils, furniture, bedding etc on it in case we do not move away to a shelter leaving our home for survival.

All the respondents living in four districts of greater Sylhet region are more or less dependent on agriculture; and they generally grow *boro* paddy once a year either on their own land or on other's land in sharecropping system. Since agricultural land remains submerged with flood water almost for 6 months, it is not possible to grow paddy more than once a year in the *haor* area. But some of the farmers cultivate mustard, pulses, potatoes and some other vegetables; and sometimes they grow wheat in post-flood situation. They never sit idle at home. If there is no agricultural activity due to flooding, either they work as daily wager or turn to be fisherman or sometimes migrate to a nearby city and work as richshawpuller. It needs to be mentioned that the villagers do not have the legal rights to fish during flooding as they do not own the *haors*, but still they fish which sometimes creates unexpected troubles for them. The villagers claim that nobody owns the *haors* as it remains dry for more than 6 months and remains inundated with flood water for the rest of the time in a year. They alleged that the local influential forcefully want to take the possession of *haors* to prevent them from fishing. Abul (37), a villager under Moulvibazar district, says,

> We are poor farmers as well as daily wager. We naturally lose our agricultural work during flooding, and try to survive on fishing. But the influential in the nearby area sometimes forcefully prevent us from fishing, claiming the *haor* as their property which is untrue. These dominating people want to see us starving with our families during the period of flooding. We cannot accept this.

Non availability of food, fuel and pure drinking water is a serious threat for the villagers living in the *haor* areas of greater Sylhet region during flooding. But they consciously store dry food, fuel and pure drinking water so that they can use them in the situation of flooding to avoid the danger at least for some days. They generally use polythene bag to store dry food and fuel; and container (indigenous earthen pot) to store pure drinking water keeping the situation of acute shortage of food, fuel and drinking water during the period of flooding into consideration. Most of the families use a portable stove for cooking purpose when their house is surrounded with flood water. But they struggle a lot to collect pure drinking water in post flood scenario as tube-well water becomes contaminated. In such cases they often use water purifying tablets given by NGO workers or government medical team to purify the drinking water so that water-borne diseases could be prevented from spreading in the *haor* area. Nurul (60), a villager under Sylhet district, states,

> We always take precaution prior to flooding by storing food, fuel and drinking water so that our family members do not go hungry and thirsty in the midst of flooding. The villagers have learnt how to tackle the situation of non availability of food and pure drinking water when flood strikes. We simply cannot push our children and other family members to death. Although lack of pure drinking water is a serious problem in post-flood situation, most families collect water purifying tablet from medical teams generally work in the area and purify the drinking water. It is an every year activity adopted by the villagers to fight flooding.

People living in the villages located close to the *haors* frequently suffer from different water-borne diseases like cold, fever, dysentery, diarrhea, skin-irritation etc. during and after flooding. Most of the villagers depend either on local pharmacy or a quack doctor for the treatment of any ailment. Some of them use indigenous herbal drugs generally produced from different plants. Begum (45), a female villager from Sunamganj district, points out,

> It becomes difficult for us to consult a qualified doctor while somebody falls sick during and after flooding as no qualified doctor is available nearby. Mostly children suffer from cold, fever, dysentery or diarrhea, and the adults suffer from skin diseases. We have a quack doctor in the village who treats our children as well as the adults. If it is only fever or cold we simply take medicine from the local pharmacy. Sometimes we use herbal medicine for the treatment of cold, cough and fever that our children suffer from.

Sanitation problem is the worst problem that the flood affected people face during flooding. Since the entire area goes under water, the inhabitants hardy find any space left where they can defecate or urinate across the village. In such a scenario, they generally create a makeshift toilet over the flood water attached with the house which is completely unhygienic but essential as no other alternative found. Sometimes they also go away by boat to find out a high ground where they relieve themselves. But the women and small children cannot do it and thus they feel forced to create a makeshift toilet attached with their house.

19.7 Building Up Resilience to Combat Perennial Floods

Flooding is perennial in the low-lying villages under four districts of greater Sylhet region. It was very much evident while interacting with the villagers that they had never felt frustrated or upset because of persistent flooding which often caused indescribable suffering for them. Flooding makes the people lose many things, and it bothers regular momentum of daily life, but can never destroy their dreams. Shakil (45), a villager from Hobiganj district, echoes,

> Flooding is a part of our life. We are no more scared of it. It is a matter of every year affair and thus we have developed a kind of resistance against it. Now we know how to face it. So, there is no problem.....it will come and go.

Jebun (50), a female living in a village under Moulvibazar district, opines,

> See, flood is a blessing for us, not curse at all. We suffer a lot due to flooding, and sometimes we are forced to migrate to a safer place when the flood is devastating. Almost everything we lose in flooding, and it happens every year. But still we bounce back, start a new life with new hopes.

It is obvious that the people have become fully habituated to face flooding each year. They are more or less found confident and courageous to confront and combat it as they take enough preparation in advance to deal with the situation. But they are also found anxious for certain matters like discontinuation of education of their children or the suffering of elderly people who cannot work and are not properly looked after during the time of flooding. Still, they overcome all the barriers and rigorously look forward to restarting a new journey of life. Rakesh (47), a villager of Sunamganj district, shares,

> We start a fresh life every year after monsoon flood. Most of us lose our house as it gets vanished in flood water. Flooding washes away our belongings and throws us at the brink of danger. Nothing could be done about it. We cannot challenge the nature. But Almighty helps us with HIS continuous blessing as we stand up, rebuild house and dream and fight again for a normal life after flooding. Unfortunately, our children always face the setback as they have to discontinue their education each year, but restart it with new enthusiasm after flooding.

Sultan (60), from a village under Sylhet district, emphatically speaks,

> Living with flooding is natural for us. We cannot escape from it as we have been living in the *haor* area generation after generation. This place is like our mother. How can we leave? We struggle a lot during the time of flooding, and sometimes we are forced to be sheltered. But ultimately we come back again to our mother as the flood water recedes. It is the blessing of our mother that helps us regain our strength and fight it back year after year. Otherwise, why should we come back again and again?

19.8 Other Resources Used for Fighting Flooding

The flood affected villagers always use multiple resources for fighting floods. The resources are both materials and non-materials. One of the important resources they utilize is network of relationship during and after flooding which provides them with myriad helps—financial and non-financial at the time when they need most. The agricultural farmers turn out to be fishermen during flooding and that is how they earn their livelihood. Affected families use a boat for fishing which has mostly been given by some NGOs, and therefore they are in a position to fish, which in turn helps them survive. Some of the inhabitants act as boatman to earn money as stranded villagers go outside the village by boat to perform their daily activities. They also dispose different types of assets like mobile phone, bicycle, jewelry, even utensils or any other possessions if the crisis during flooding deepens. Many of the villagers often feel forced to be dependent on food relief provided by NGOs and different government organizations during the time of flooding which is considered as a great help, especially at the initial phase of flooding. Spending money from savings to cope with the crisis of flooding is a common practice among the villagers. Of 40 respondents, 33 were found involved in micro credit program of NGOs which, according to their opinion, was beneficial to handle post flood shock. Borrowing money from kin, neighbors and friends is also common in flood affected *haor* areas. Women often travel long distance in search of drinking water and firewood for the family as the area remains submerged with flood water. They preserve dry food, fuel, candles, matches, ropes and medicines inside the house to fight the situation of flooding. The first step adopted by the affected people in post-flood life is to repair the house and sometimes plant banana and other trees around the house aiming to coming back to normalcy with full strength, energy and passion.

19.9 Discussion and Conclusion

Greater Sylhet region which includes Sunamganj, Moulvibazar, Hobiganj and Sylhet district is low-lying and highly vulnerable to flash flooding. This low-lying area is popularly known as *haor* area, and the people living in different villages located close to this *haor* area suffer enormously due to frequent floods that occur every year. The entire *haor* area remains under flood water almost for 6 months a year, and thus the residents of this area go through repeated suffering which is often unbearable for them. Although the suffering of the people is multifarious and that too is yearly, people still do not lose hope, rather fight hard to regain life amid flooding. Findings of the study adequately show that flood affected people perform different activities to overcome the adverse situation that is created due to frequent floods. Since top-down approaches followed by the state fail to mitigate flooding timely and effectively (Adnan 1991; John 1998), indigenous approaches adopted by the suffering people have been emphasized for incorporation (Blaikie et al. 1994; Sanderson 2000) into flood mitigation strategies. Most of the flood affected people raise the platform of the house before flooding which is an indigenous approach and is found adopted to save lives and shelter in many other studies (Islam 2001; Paul and Routray 2010; Pulla and Das 2015; Thompson and Tod 1998; Rasid and Paul 1987). Elevating bed with bricks and tying it with a strong wooden pillar inside the house is another strategy followed before flooding to secure the life of mostly children in all the villages under the study. But the families feel forced to migrate to a safer place if flooding goes from bad to worse, poses a serious threat to the lives of family members. Flood affected households are sometimes compelled to borrow money from relatives, neighbors and friends in order to buy foods in the midst of flooding. Similar findings have been presented by some previous researchers (Ninno et al. 2001; Paul and Routray 2010; Pulla and Das 2015; Sultana and Rayhan 2012), showing coping mechanism of flood affected people. Some families were found who had to take micro credit from NGOs to tackle the post flood crisis. Zaman (1999) however finds credit taken from traditional sources is more effective than that of micro credit taken from NGOs, though the current study is unable to confirm it. The villagers rear livestock and poultry to sell them before floods so that they can face the difficult times during and after flooding. Sometimes they need to sell other assets like land, mobile phone, jewelry, bicycle, utensils etc., and also reduce the consumption of food or skip number of meals in a day and/ or buy cheap foods, borrow money from some sources to cope with the situation of unemployment created through flooding. These findings may be substantiated with the results of many previous studies (del Ninno et al. 2003; Haque and Zaman 1993; Khandker 2007; Maxwell et al. 1999; Sultana and Rayhan 2012) conducted on the same issue. Although villagers are mostly agricultural workers and dependent on cultivable land for earning livelihood, they often become fisherman during flooding as no other option available for earning. Food relief given by the government or NGOs in the time of flooding helps the flooded households stay alive. They also store dry food, fuel, and drinking water well ahead of flooding so that they can survive in the face of devastating floods. In case of emergency, affected people are forced to spend money from their savings, especially when there is no work available. Many people including children suffer from water-borne diseases like cold, cough, fever, dysentery, diarrhea etc. during and aftermath of flooding. The sick mostly depend on indigenous herbal medicine, quack doctor and local pharmacy for treatment. After flooding, the first task they perform is to repair the broken house or build a new one if the old one washed out. Many researchers (Frankenberger 1992; Paul and Routray 2010; Sultana and Rayhan 2012; Pulla and Das 2015) have found similar pattern of coping strategies adopted by the flooded households.

It is obvious that the people living in the low-lying area of greater Sylhet region constantly fight to cope with the situation of flooding which is perennial and believed to be never ending. The suffering people seem to be creative as they adopt strategies according to demands of the situation in the midst of devastating floods that assault them every year. Perennial floods not only produce critical conditions but also offer communities with variable strengths to cope and adapt (Pulla 2013; Reivich and Shatté 2002). Flood affected people always grow strengths in critical conditions of flooding that help them fight better to cope and adapt with the crisis. Like other studies (Corbett 1988; Paul and Routray 2010; Pulla and Das 2015) present study adequately shows that the people move intelligently as they take preventive and mitigative initiatives sequentially on the basis of necessity in the context of destructive floods. Flood is a reality which brings untold misery, destructions and sufferings for the people living in the region. But most important aspect of this reality is that people are not broken hearted, frustrated or demoralized, rather they are courageous, fighting-prone and resilient—always remain ready to combat the situation of any nature. They do not fear the devastation of flooding rather they manage to cope, tackle and strive. Escaping the danger posed by recurring flooding is not their mission; instead they confront it with their full strength, make all out efforts to find a new life—a life with fresh hopes and dreams. So, fighting floods is natural—a fighting that continues for their survival.

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