DOCTORAL SCHOOL IN CIVIL, ENVIRONMENTAL AND MECHANICAL ENGINEERING

Spatial planning to integrate climate change adaptation at local level

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"Only within the moment of time represented by the present century has one species -- man -- acquired significant power to alter the nature of the world."

(Rachel Carson, *Silent Spring*, 1962)

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(Parveen Kumar)

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Summary

Climate change is directly or indirectly affecting cities, regions or even nations in multiple ways. Impacts are exponential and repetitive with increased instability of climate pattern, socio-ecological systems, increased inequalities and distribution of resources. It is therefore necessary that social and economic hubs and potential resource rich region should become the catalyst that encourages the focus on climate change policies. Despite having various international and national climate change frameworks and forums it is unclear how international, national and even local governments develop response actions to climate concerns and integrate them into different spatial scales. Developing and mainstreaming effective response actions to climate change into numerous sectors, cross-sectoral policies is a complex issue which has plagued policy makers at different spatial scales and on different policy arenas.

In order to efficiently integrate and sensitizing society towards climate change issues, decision makers and different stakeholders have to develop insightful information bases, share awareness of climate change risks, vulnerability patterns and finally develop response actions at all level of policy preparation through policy integration, implementation or structural reforms.

This study contributes towards understanding climate change risks and perception within spatial planning policies at local level. This has been undertaken by investigating, testing or developing real spatial planning policies, vulnerability assessment frameworks and decision support systems that aim to improve current spatial planning tools intended at building climate resilient living spaces. This study was divided into three main stages 1) To develop and test an assessment framework to track integration of climate change issues into spatial planning, 2) To identify hot spots of climate change at urban/regional levels by applying spatial vulnerability assessment tools and 3) To apply eco-system based adaption responses to climate change in an urban region and identifying barriers.

Drawing the case study from India, in the first stage, an attempt was made to understand how spatial plans in India are incorporating climate change issues and identifying potential gaps. Spatial plans across various cities in India were examined with the help of a review framework that was developed upon Moser and Loer's (2008) work on "Managing climate risks". The second stage presents a climate change vulnerability assessment framework and its working methodology at local spatial scale, considering three main components: exposure, sensitivity and adaptive capacity. The vulnerability assessment framework was applied to an urban area in India, namely, Bangalore and a hill district of Eastern Himalaya namely Darjeeling. In the final stage of this study, ecosystem services based adaptation responses within spatial planning was studies to

understand how it can increase adaptive capacity and address climate changes issues.

The results of this study identified key concerns to climate change issues and its integration in India. The policy analysis shows that the role of spatial plans to integrate climate change issues at local levels like urban areas and regions in India are still limited. Local policies and spatial plans shows low level of awareness, moderate level of analytical capability and limited action responses to integrate climate change issues at local level. Spatial policies in India are still limited to physical and economic issues and undermine the issues of climate change. The application of vulnerability assessment framework demonstrated that it successfully provided a spatial assessment of climate change vulnerability patterns. The spatial pattern of vulnerability identifies areas requiring urgent attention to adaptation action, enabling policy intervention and prioritizing action. At the same time an analysis of the perception of people also confirmed the results of vulnerability assessment at local level. Finally the results showed how ecosystem services based response actions when applied within spatial planning can play an important role to mitigate the effects of climate change and adapt to local climate concerns with least negative repercussions.

The findings of this study creates a platform for discussion on decision making process and the potential aspects where climate change issues can become a part of spatial planning policy. Climate change mitigation and adaptation for short terms may fulfill objectives for current climate scenarios but may impose externalities in future. So, policy makers and local development organization need to carefully narrate future climate resilient scenarios. This study is the reflection of the interrelationship between the existing information bases, knowledge gaps, policy preparation practices, analytical capability, participation and technological innovation in climate change integration at local spatial scale.

Chapter 1

1 Introduction

1.1 Background

It is predicted that cities will account for 60% of the world population by 2030 and increase by 70% by 2050 (UN habitat, 2015). As the world population is transitioning from rural to urban regions, these areas are becoming hubs of human induced changes fuelled by development and in turn affecting the environment around it. With fast paced urbanization as well as aging and inadequate infrastructure, cities are likely to struggle in the coming decade to cope with the stress of water, sewage, transportation and other basic infrastructure. This will be further exasperated by the changing climate and exposure to extreme climate events such as hurricanes, typhoons, droughts and floods. Climate change is and will continue to critically impact the socio-economic fabric of the urban system (Rosenzweig et al., 2011). A range of impacts will be observed in the form of increased urban system instability, declines in socio-economic productivity and increased inequities and distribution of resources. It is therefore necessary that urban areas become centre of climate change policies rather than just national scale initiatives. The discourse on climate change initiatives at urban level is only recently gaining momentum. Year 2014 was a landmark in these initiatives with mayors from 40 cities pledging to fight climate change by committing to reduce GHG emissions and account for their progress annually. The key partners of this global compact were C40 Cities Climate Leadership Group (C40), ICLEI – Local Governments for Sustainability (ICLEI) and the United Cities and Local Governments (UCLG) and additionally supported by the UN-Habitat. This initiative is expected to help policy makers in cities and financial institutions that aid in infrastructural development to improve their understanding on the potential impacts of climate change at city level, where support can offered and funding directed. With the global community acknowledging the importance of climate change initiatives at city level, it is becoming apparent that urban areas, small or big, could be one of the key catalysts to engage in mitigation actions to climate change as well implementation of adaptation measures.

Increased variability and instability of climate stimuli have adverse impacts on the operation of urban systems and its hinterlands (Field, 2012; Field et al., 2014). The consequences range from loss of agricultural production, increased dry spell and water shortages, loss of lives and livelihood during the extreme events like floods, heat waves, droughts to second order impacts of climate change in the form of loss of local ecosystem, increased number of health problems, economic inequalities etc. (Rannow et al., 2010; Rosenzweig et al., 2011). The vulnerability of cities to climate change is also closely linked to its geography and its latitudinal location. While the latitudinal location determines the energy usage of the cities in the form air conditioning, heating systems and maintenance of artificial temperatures in buildings and housings, the geography of the urban areas determines its proximity to specific eco-zones and the issues inherently appended to it. For example, historically a large number of cities have been developed close to lakes, river and seas where the problem of flooding is becoming a frequent issue due to impermeable surfaces, lack of green spaces for absorption and ominous drainage conditions. In addition to these two factors, people in developing nations facing poverty, disparity, health risks and political and economic instability are more severely impacted by climate change (Baker et al., 2012a; Satterthwaite, 2007). For example, slums in big cities are high-risk sites , improper housing on floodplains or steep slopes will be the first to be affected during floods, landslide and other extreme weather conditions (Revi, 2008; Satterthwaite, 2007). Changes in climate variables not only affects physical assets of people or urban area but also affects livelihood, capacity stock to local institution and social network of urban systems (Habitat, 2011a). All these factors result on a low baseline resilience of urban systems to climate change and show that urban regions are the spatial regions where vulnerability are most visible and apparent (Field et al., 2014; Habitat, 2011a; Satterthwaite, 2007). Altogether, these critical issues of climate change in the urban system pose the question on how to develop effectively or integrate climate change adaptation response actions within local policies of urban regions.

The early impacts of climate change focused on ecosystems and agriculture and scientist all but ignored the effects on cities which were thought to be inherently adaptable (Comment, Nature 2010). It is only in the past decade that various organizations, government bodies and scientists have begun to assess the first and second order impacts of climate change at city level to develop complex models at small scales that can factor in the urban stressors such as heat islands, air pollution and urban design (Rosenzweig et al., 2011). Even then, majority of studies and assessment reports on the emerging effects of climate change have been climate science-driven (Preston et al., 2011; Rannow et al., 2010). There has been an urgency to act on the scientific assessments of climate change on cities and integrate the know how into policy making (Field et al., 2014). This is easier said than done, given the lack of consensus on methods and financial or human resource disparity among different nations, making climate change a difficult entity to integrate into policies (Satterthwaite, 2007). For example many fast growing developing countries in Asia, Africa and South America are facing severe impacts of climate change but lack the necessary financial and natural resources to act on climate change issues (Field et al., 2014; Habitat, 2011a; Revi, 2008). On the other hand, majority of developed countries of the world although being the key green house gas emitter stress that the developing countries need to take actions without giving them the financial support necessary to undertake such initiatives (Corfee-Morlot et al., 2009; Habitat, 2011a; Urwin and Jordan, 2008).

Integrating climate change issues into general planning policy to specific action plans has become a “wicked problem” for decision makers across the world (Baker et al., 2012a; Brooks et al., 2009;

Field et al., 2014; Urwin and Jordan, 2008). Today most international research organizations are investigating and developing frameworks to integrate climate change at all levels of policy processes that will support mitigation, adaption and sustainable development (Lim et al., 2005). Climate change issues have started emerging in mainstream focus areas in general policy making process across the world (Brooks et al., 2009; Field, 2012) and a number of authors have addressed how climate change can be integrated into the planning process (Lim et al., 2005; Urwin and Jordan, 2008; Wilson and Piper, 2010; Yohe and Tol, 2002).

In order to effectively integrate and sensitizing society towards climate change issues, decision makers have to share awareness, recognize changing climatic variable and possible impacts on socio-ecological system of the region (Snover et al., 2007). To integrate climate changes issues into policies at various spatial scales and preparing the society to plan for the possible impacts of climate change, policy makers and decision maker need to recognize key concerns, viz. awareness of climate change drivers and impacts, analysis of effects in the form risk and vulnerability and finally response action at all level of policy preparation through policy integration, implementation or structural reforms at local level (Baker et al., 2012a; Moser and Luers, 2008). These three components are defined as follows:

Components to integrate climate change into spatial policies	
Awareness	Comprehensive awareness of the key drivers of changing climate variables and its consequences in needed in order to make an informed decision (Lindseth, 2004).
Analysis	Involves assessment of risk, impacts at various spatial scales by integrating, quantifying, and synthesizing available information (Füssel and Klein, 2006; Snover et al., 2007).
Action	Attempts to use analysis to develop target policies and plans to address locally identified climate change risks and steps that the local government plan to employ to reduce climate change vulnerability (Biesbroek et al., 2010; Biesbroek et al., 2009; Tompkins et al., 2010).

Definitions: Climate change impacts and responses	
Climate change Impacts	The effects of climate change on natural and human systems
Potential impacts	All impacts that may occur given a projected change in climate, without considering adaptation
Residual impacts	The impacts of climate change that remain after adaptation measures have been taken
Mitigation	Intervention (by government, institutions, companies etc.) to reduce emissions of greenhouse gases to the atmosphere; it includes strategies to reduce greenhouse gas sources and emissions and enhancing greenhouse gas sinks (It is also referred to as reducing the anthropogenic forcing of the climate system)
Adaptation	The adjustment in natural or human systems in response to actual or expected climates and weathers, or their effects, in order to moderate harm or exploit beneficial opportunities. Distinct types of adaptation: anticipatory,

	autonomous and planned adaptation
Vulnerability	Vulnerability is the degree to which a system is susceptible to, and unable to cope with, adverse effects of climate change, including climate variability and extremes. Vulnerability is a function of the character, magnitude, and rate of climate change and variation to which a system is exposed, its sensitivity, and its adaptive capacity.
Source: IPCC, 2007c: Appendix- Glossary	

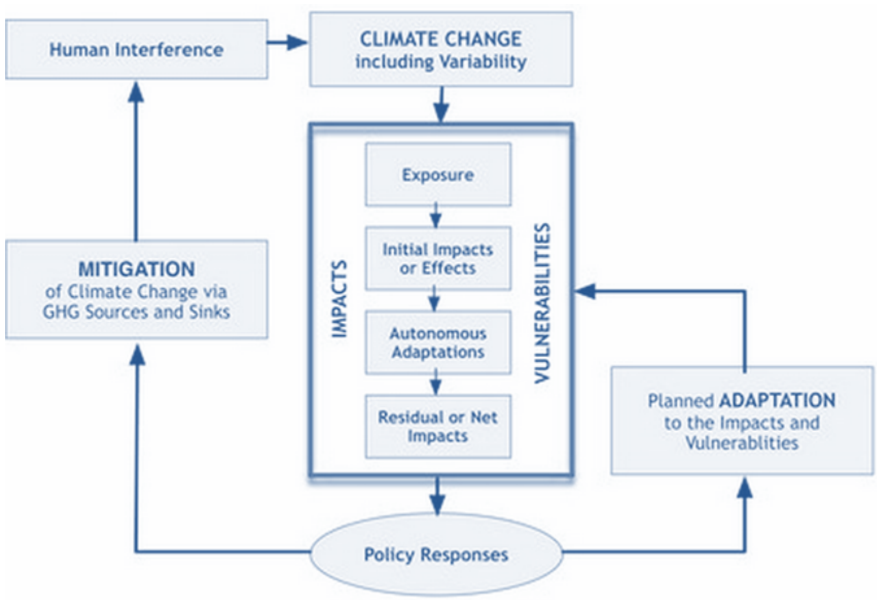

Figure 1-1: Relationship between vulnerability, impacts and policy response (IPCC 2001)

1.2 Role of spatial planning to manage climate change issues

Spatial planning has been seen as an instrument and a framework that plays a critical role for sustainable development at various scales. The modern planning practices emerged after the European Industrial Revolution. Since then spatial planning practices have been changing as problems arise from rapid urbanization. In the past few decades spatial planning policies and processes have been undergoing a more widespread change to its policy structure and objectives. Initially, spatial planning practices concentrated on protecting health and well-being. Under the basic planning provisions stressors included developing sewerage, control of sprawl, location of industry and the creation of pleasing aesthetic spaces. Recently, spatial planning has been updated to include environmental protection, public participation and the imperative sustainable development in a 'broad sense' (Bruff and Wood, 2000; Bulkeley and Betsill, 2005; Owens, 2004; Owens and Cowell, 2011). In 2002, the world summit on sustainable development emphasized on to importance of specific aspects of climate change assessment and implementation. In most developed and developing countries spatial planning policies for climate change issues are not seen as potential policy instrument. Indeed, many of the principles that had begun to creep into land use and transport planning during the 1990s was limited to reduction of emissions of greenhouse gases (Kumar and Geneletti, 2015).

The potential scope of spatial planning to combat climate change is huge because it is not just an environmental problem but deals with a myriad of issues spanning distribution and access to all shared resources such as water, atmosphere, land and energy. Therefore, different authors and researchers have been debating on the most effective ways in achieving sustainable development and address the problems of climate change. For example, the IPCC insists that the effectual way to combat climate change is by influencing land use regulations, infrastructure planning and managing building plans (IPCC 2007). The Stern report on the other hand argues that the real operational measures should include taxation, trading, carbon pricing and technology innovation (Stern 2007. In contrast the European union's White Papers on adapting climate change has a more holistic view articulated as "A more strategic and long term approach to spatial planning will be necessary, both on land and on the marine areas, including transport, regional development, industry, tourism and energy policies" (CEC, 2009a).

At national level some countries like the United Kingdom, Netherlands and Canada have placed emphasis on the role of spatial planning in delivering emission reduction, increasing adaptive capacity and decreasing vulnerability to various climate change events (Wilson and Piper, 2010). For example, the UK Climate Change Programme, Integration of water board and spatial planning in Netherlands and Canadian Municipalities has placed emphasis on the role of integrating spatial planning and environment issues into strategic planning documents or development control decisions. Some individual local governments across the UK like Leicester, Newcastle and Kirklees, are also developing climate change strategies to integrate climate change concern into land-use planning policies and decisions (Bruff and Wood, 2000; Wilson and Piper, 2010).

Currently different national and local governments see the need for precise definition of climate change risk (Field et al., 2014; Habitat, 2011a) and mostly need to formulate their policies that encourage environmental and climate-sensitive development instead of just advocating no development. Local governments, being the key centres of policy implementation, have several ways of influencing climate change impacts through mitigation or adaptation like control the conversion of energy to non-carbon sources, influence resident and local business behaviour through education, tax, and fee policy and other economic incentives or disincentives (Condon et al., 2009; Corfee-Morlot et al., 2009; Lindseth, 2004; Revi, 2008). However, most significant influence that the local governments can make are through decisions on urban form, primarily through urban planning and land use regulation (Condon et al., 2009; Tompkins et al., 2010; Urwin and Jordan, 2008). Local planning guide infrastructure investment and development control, that have advance mitigation impact on climate change issues (Wilson and Piper, 2010). Policy makers, regulators political constituents and stakeholders at different spatial scale require clear understanding and decision support tools that illustrate climate change drivers, concern and impacts so they can make sound, locally relevant climate change strategies in form of mitigation or adaptation action response (Tompkins et al., 2010; Urwin and Jordan, 2008). Currently wide range of tools exists, a few of which have the capacity to work simultaneously at both the regional and local scale, or to capture the multiple consequences of regulatory decisions (Condon et al., 2009). However, they lack the ability to model real-time information and policy process implications. The integration of climate change issues into spatial planning requires an in depth research at not only a theoretical level, but also a practical level dependent on geography and spatial scale.

1.3 Key gaps

Developing effective climate change policies and mainstreaming them into various sectoral, cross-sectoral policies is a complex issue (Biesbroek et al., 2009). Having said that local level spatial systems have the potential role to act effectively on climate change issues in a number of ways (Biesbroek et al., 2009; Hurlimann and March, 2012). At local-level spatial plans are the basic policy framework that shapes social, economic and physical development of cities and at the same time interaction of these aspects become the main drivers of climate change issues at various scales (Wilson and Piper, 2010). Hence spatial planning has a bigger role to play at the local level to climate change issues as it specifies the interrelations and the effects of policy measures on spatial development and it can possibly act as an effective instrument for climate change adaptation response at local level (Wilson, 2006; Wilson and Piper, 2010). However recognising the spatial context and focus of this study there are a number of key challenges to formulating and integrate climate change adaptation solutions at local level. We are highlighting a few of these key challenges in a developing nation like India.

1.3.1 Translation of climate science knowledge to spatial plans at various spatial scales

Majority of cities in developing nations are still lacking the appropriate scientific information and knowledge to integrate climate change issues into current spatial or general policies (Biesbroek et al., 2009; Hurlimann and March, 2012). Majority of information and data available to the government, research organisations at international or national levels are at broad spatial scales and the way information is developed and produced by climate scientists limits its use to make decisions at local level (Opdam et al., 2009; Rannow et al., 2010). The scientific community and planning bodies at local level follow different philosophies (Bulkeley et al., 2009; Rosenzweig et al., 2011). While the scientific community adopts an evidence base, cause and effect chain approach, exploring historic and present data on climate stimuli, the planning community is focused on generating integrated solutions that cover all issues addressed by spatial development (Pyke et al., 2007; Rosenzweig et al., 2011). Hence, there is a need for communication between scientists and decision-making that bridges the gap to formulate knowledge based decision support systems for developing climate change action at local level (Pyke et al., 2007).

1.3.2 Lack of understanding of the core issues

Global warming and climate change has become one of the main issues of discussion in the past decade among climate scientist and policy maker based on scientific evidence. While earlier climate change concerns were perceived as environmental problems, it is now being considered to influence the welfare of people based on scientific evidence. Therefore, IPCC and other key climate policy focus organisations are trying to educate the society, local and national governments about climate change issues and its impacts. While researcher are exploring the cross-sectoral interactions of climate change issue to understand its complexity, they are also working on gathering the scientific know how of the effects of climate change between different stakeholders of the society to build resilient and sustainable cities (Biesbroek et al., 2009). Even today, new learning and concerns are brought by different stakeholder involved to reframe the role of society in climate change (Haas, 2004; Jasanoff, 2004).

1.3.3 Lack of tools and methods at various spatial scales

According to the Intergovernmental Panel on Climate Change (IPCC) fourth assessment report (Field, 2012; Field et al., 2014), urgent action needs to be taken on climate change through various adaptation responses along with mitigation strategies in our policy making process at all levels of spatial scale. This is especially true at local levels, because such initiatives and policy implementations need a bottom up approach. However, such response action is not an easy undertaking because developing climate change response action at local level requires in-depth knowledge of climate change vulnerability and its patterns. Unfortunately, not all nations and local governments across the world have sufficient knowledge, awareness, analysis capability and conducive environment to work on climate change issues at the same level, specially in developing nations (Preston et al., 2011).

Lack of standardized methods for vulnerability assessment for local level or at higher spatial scales has become a fundamental challenge for developing sufficient knowledge and awareness for climate change issues (Preston et al., 2011). It has become a practical challenge to apply and replicate available vulnerability assessment methods at local spatial scales and regions (Hinkel, 2011; Preston et al., 2011). Few other important concerns are credibility, comparability and transferability of sector-specific vulnerability assessment for integrated assessment methods

(Hofmann et al., 2011). In addition, vulnerability assessment methods defined for higher spatial scales are difficult to implement at local levels (Holsten and Kropp, 2012; Kumar et al., 2013; Rannow et al., 2010). This is evident from the fact that the few comprehensive vulnerability assessment studies at regional spatial scales are very general and at the same time demonstrate the difficulty in translating output and knowledge into policies given that they do not define degree and magnitude of the results (Füssel and Klein, 2006; Laukkonen et al., 2009; Tol and Yohe, 2007). The absence of a standardised vulnerability assessment framework, to identify extent and magnitude of impacts of climate change for the decision support system for planning policy at local level, is crucial.

1.3.4 Policies and decision interplay

Including different perspective and developing collective conviction to integrate and formulate adaptation response action is the key challenge to spatial planning practices. Planning is exercised within and through government, and is subject to influence from various stakeholders, and it become a matter of trade-off, (Forester, 1999; Hurlimann and March, 2012). Planning decision relies on a range of actors, spatial context, market and collective choice. Wrong choices and decisions lead to policy failures at multiple scales and face severe repercussion (Hurlimann and March, 2012). Even having sufficient information, decision are based on politics and market interests (Roaf et al., 2009), institutional path dependency (Bulkeley et al., 2009), convenience of decisions (Howard and Monbiot, 2009), functional responsibilities and capacity through which climate change concepts can be transferred from policy principles into practice (Bulkeley, 2006; Wilson and Piper, 2010). Addressing these barriers will be critical for planning if it is to effectively facilitate adaptation actions to climate change at local level.

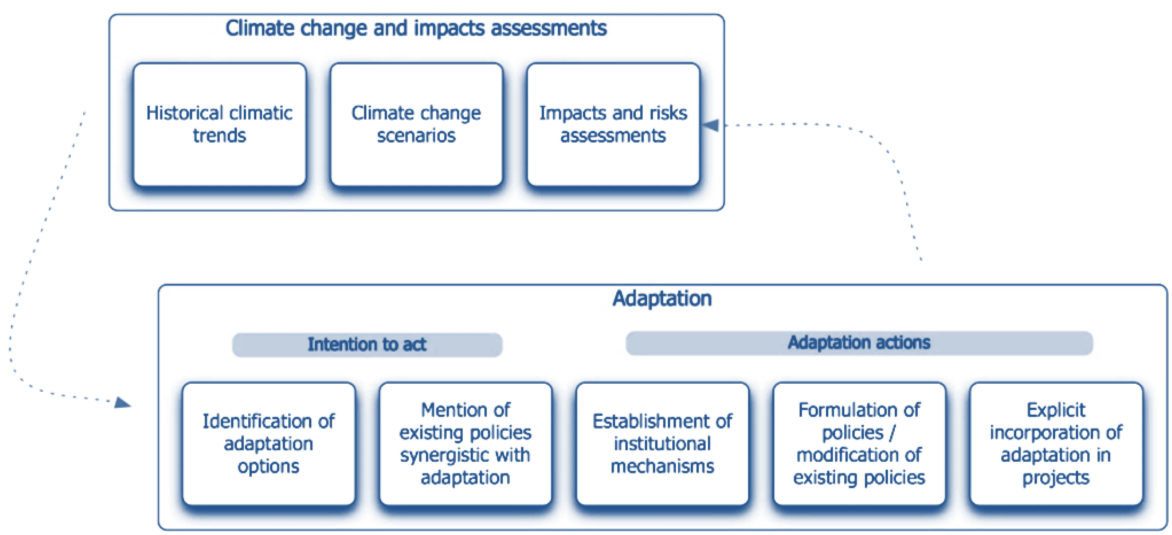

Figure 1-2: Main stages of city based climate change adaptation. Based on (Gagnon-Lebrun and Agrawala, 2006)

1.4 Research objectives and underlying questions

The aim of this study is to contribute towards understanding climate change risks and perceptions in spatial planning policies at local level. By investigating spatial planning policies, an assessment framework and decision support system will be built that aims to improve current spatial planning practices and planning tools intended at building resilient living spaces. The main research objectives of this study and the underlying research questions are as follows:

Objective 1	Objective 2	Objective 3
To develop and test an assessment framework to track integration of climate change issues into spatial planning.	**To identify hot spots of climate change at urban/regional levels by applying spatial vulnerability assessment tools.**	**To apply eco-system based adaption responses to climate change in an urban region and identifying barriers.**
• How is the knowledge of climate science transferred into spatial planning policies at local level? • To what extents are spatial plans and policies are appropriate policy tools to integrate climate change action at local spatial scales? • What are the key gaps and shortcomings to address climate change issues by spatial plans?	• What is the basis for the assessment of vulnerabilities and risks from climate change and its usability at different spatial scales? • How to assess vulnerability patterns, and generate maps of spatial vulnerability to aid in prioritising response actions for spatial planning policies at the urban/regional scale? • How spatial vulnerability pattern and assessment of climate change differs from the perception of people, social context and institutional arrangements?	• How to understand the relationship between ecosystem services and local climatic vulnerability by investigating the effect of composition and configuration of local ecosystem services? • What are the ecosystem-based adaptation response to climate change in selected case study in India and its acceptability to the community

1.5 Thesis outline

The dissertation consists of 7 chapters including the introduction and synthesis. Chapter 1 is the general introduction to the dissertation including the background and key gaps in research. The main chapters numbered 2, 4, 5 and 6 are written as stand-alone manuscripts dealing with a specific research question. The structure and content of these chapters have largely been retained in form in which they have been prepared (either for submission or under revision, or accepted as papers in peer reviewed journals). The remaining chapter, numbered 3 are bridge chapters to provide more details about the study areas and discuss some of the interesting results from the intensive field work. Finally chapter 7 is the synthesis, which summarizes the findings of the chapters and concluding thoughts on the topics of this dissertation. The interrelationship of the main aim, objectives of the thesis with chapters is also illustrated in Figure 1-3.

The title of the chapters is as follows:

Chapter 1: Introduction

Chapter 2: How are climate change concerns addressed by spatial plans?

Chapter 3: Introduction to the case studies

Chapter 4: Spatial assessment of climate change vulnerability at the city scale: an overview of Indian city Bangalore

Chapter 5: Spatial assessment and perception of people to climate change in Darjeeling Himalaya

Chapter 6: Assessing importance of ecosystem based policies for adaptation to climate change in Darjeeling Himalaya

Chapter 7: Synthesis

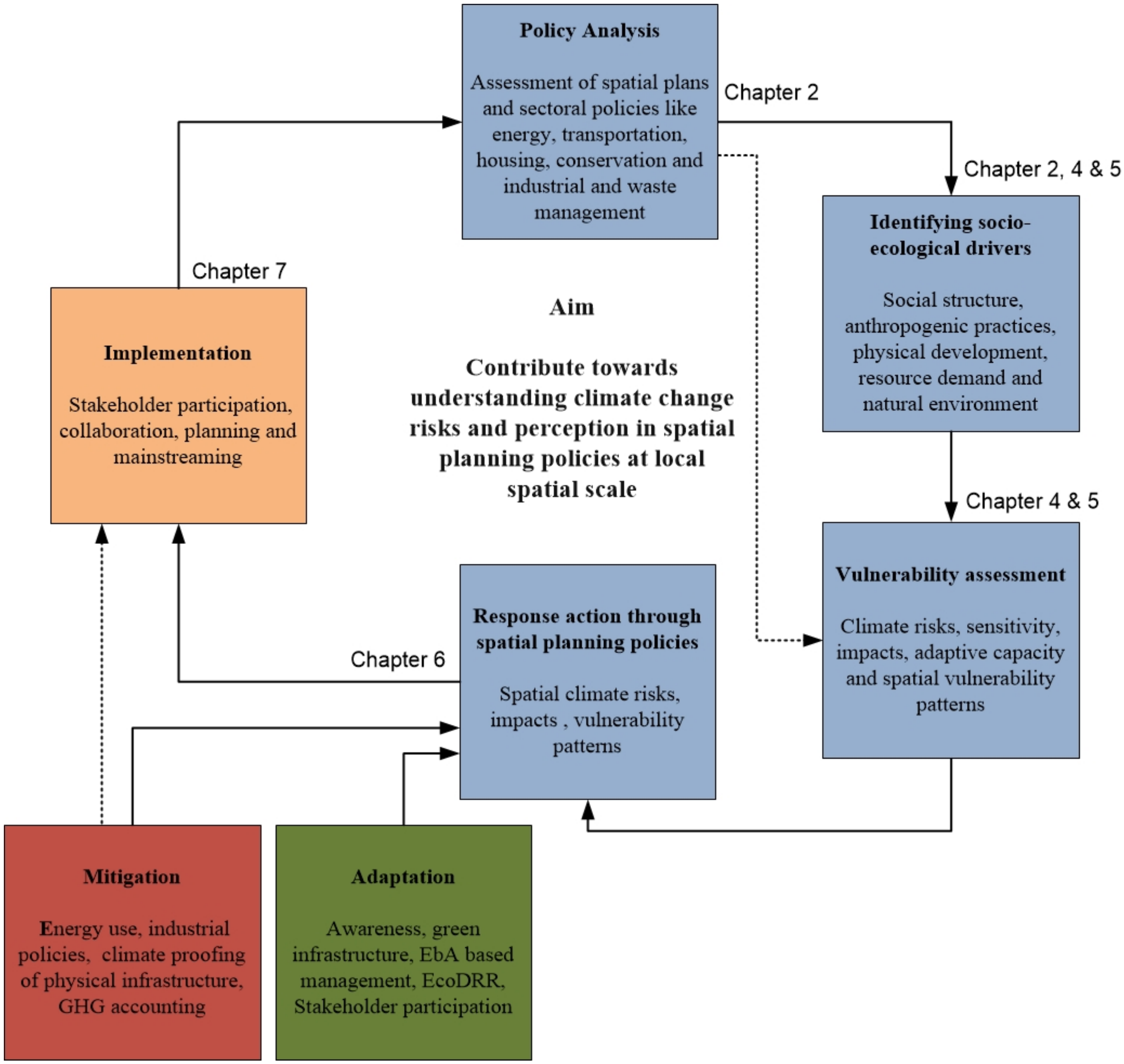

Figure 1-3: Interrelationship of the aim, objectives of the thesis with policies

Chapter 2

This chapter is based on: Kumar, P., Geneletti, D., (2015). How are climate change concerns addressed by spatial plans? An evaluation framework and an application to Indian cities. Land Use Policy 42, 210-226.

2 How is climate change issues integrated into spatial plans?

2.1 Introduction

Addressing climate change issues requires different response actions at various spatial scales (Preston et al., 2011; Neil Adger et al., 2005). So far these responses have been in the form of international agreements, policy instruments, mitigation and adaptation policies focused especially on the global and national scale (Field et al., 2012; Parry, 2007). However, it has been observed the majority of policies and action response developed at global and national scale are unfit to act on climate change issues driven and experienced at local scale (Measham, 2011 ; Neil Adger, 2005). Climate change is a global concern but the drivers and effects are felt at regional and local scales. The goals pursued at the higher scales often clash with the problem faced at local scale (Rannow, 2010; Urwin, 2008). Therefore the issues of climate change should also be analysed and addressed at the local level.

A few studies from the United Kingdom and European Union show that developing effective response actions for climate change at local level may be beyond the capacity of local governments (Wilson, 2006). These observations emphasize the fact that there is a lack of awareness and knowledge on addressing climate change issues at the local scale (Moser, 2008; Neil Adger, 2005), information gap and technical expertise (Wilson, 2006), low level of political support and financial resources (Urwin, 2008; Moser, 2008) and significant disagreement among various stakeholders on climate change issues (Hulme, 2009). According to Wilson (2006) to incorporate climate change response actions at local level, development authorities require detailed information about climate change issues, climate change vulnerability, financial resources, technical expertise and political as well as public participation.

Developing effective climate change policies and mainstreaming them into various sectoral, cross sectoral policies is a complex issue (Biesbroek et al., 2009). Having said that at local scale, spatial policies have the potential role to effectively act on climate change issues in a number of ways (Biesbroek et al., 2009; Hurlimann and March, 2012). Spatial planning deals with two core aspects. First is to foster the community and institutional vision for future socio-ecological development under legal endorsements. The second is to control land use change and spatial development of the local area through allocation of space for various activities (Hurlimann and March, 2012). For example, spatial plans directly control the physical development of the city through urban design policies by giving permission for various infrastructures like transportation, industries, housing and resource allocations for social and public amenities. It also provides guidance for land use change that affects ecological aspects in the form of land fragmentation, ecosystem, biodiversity and other natural resources. Thus local-level spatial plans are the basic policy framework that shapes social, economic and physical development of cities and at the same time interaction of these aspects become the main drivers of climate change issues at various scales (Wilson and Piper, 2010).

Hence spatial planning has a bigger role to play at the local level to climate change issues as it effects of policy measures on spatial development and it possibly has the potential to act as an effective instrument for climate change adaptation response at local level (Wilson, 2006; Wilson and Piper, 2010).

The goal of this paper is to critically review the incorporation of climate change issues in spatial plans across cities in India, and identify significant gaps and shortcomings. This study can potentially aid local governments to identify key areas where innovative response actions are required to foster a better planning practice in the future.

2.2 Study context

2.2.1 Emerging patterns of urbanization in India and effects of climate change

India is among the fastest growing economies of the world and has a target of 9 to 10% growth is GDP. The Planning commission 2008 categorically stated that this rate of growth depended on a vibrant urban sector which contributed to as much as 62% of the GDP. The current Five Year Plan (2012-2017) therefore considers this urban transition as a significant challenge requiring massive growth in infrastructural and services (Bhagat, 2011). In terms of demographics, urban growth refers to the increase in the percentage of population living in the urban areas. There has been a steady increase in the population in urban areas in different states in India (Table 2-1 and Figure 2-1).

Table 2-1: Trends in Urbanization in India (1961-2011)

Census Year	Urban Population (in millions)	Percentage Urban
1961	78.94	17.97
1971	109.11	19.91
1981	159.46	23.34
1991	217.18	25.72
2001	286.12	27.86
2011	377.10	31.10

Source: Adapted from (Bhagat, 2011) and census of India (various years)

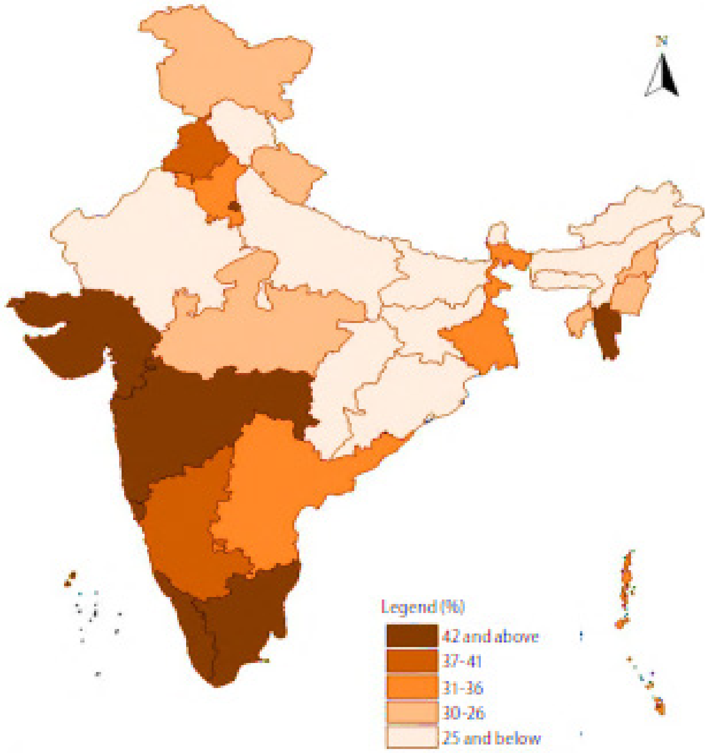

Figure 2-1: Levels of Urbanization in India (2011)

The reason that the level of urbanization is important in the discourse in climate change is that, they can both catalyse climate change by encouraging growth, emissions and consumption and also be affected by climate change by encouraging population migration through droughts, floods and climate induced extreme weather events. Since cities have a characteristic of being locked in terms of changes in emissions and spatial characteristics that require at least decades to show any significant affects on climate change; developing countries like India have the power to change the way cities are build or expanded so that they can be sustainable and adapted to the effects of climate change. Big cities in India such as the metropolitan areas of Delhi, Kolkata and Mumbai may be beyond any type of mitigation action and the populations therein will have to adapt to the effects of climate change. But India can benefit from the new age sustainability revolution by incorporating international knowledge in planning smaller and middle sized urban areas in terms of being energy efficient, using renewable energy, waste water recycling, green infrastructure etc.

Risks in Indian cities due to climate change induced vulnerabilities

- Loss of Livelihood due to disruption of work, displacement and health reasons. Indirect losses include loss of financial assets, land rights, house or household rights and inadequate identification for rural migrants
- Disruption of community safety and support due to displacement and forced migration
- Less resilient population to potential climate distress due to repeated risk exposure, negative net income and loss of assets
- Low access to public services in overpopulated urban areas or urban hinterlands leading to high expenditure for basic needs such as water, electricity and health
- Greater vulnerability due to unsound debt system, economic inequality, political patronage and organized crime which might increase in times of crisis.

Source: Adapted from Mukhopadhyay and Revi, 2009

2.2.2 Climate change discourse in India and international standing

India is the third largest emitter of Green House gases in the world and it is predicted that its emission will increase by 3.4 % per year and India will account for 10% of CO_2 emission by 2035 (IEA, 2013) . International pressure is therefore mounting on India to sign treaties that legally binds it to reduce emissions. Scholars in India have however maintained that international agreements should be based on historic and per capita emissions with the developed countries not only reducing their emissions first but also providing financial remunerations for mitigation and adaptation actions in developing countries (Thaker and Leiserowitz, 2014). This stand among Indian climate change advocates has been prevalent since the late 1980's when the Indian government was pushing for a market oriented economy to accelerate growth. In spite of this strong position, scholars do recognise that India is among the most vulnerable countries in the world (Cruz, 2007) with at least half the population dependent on agriculture or other climate sensitive sectors (statistics, 2010). Moreover, the current urbanization model in India is unsustainable and unless alternative models are put into place, urban centres in India will significantly affect the vulnerable and also be responsible for the increase in massive amounts of GHG emissions (Mukhopadhyay and Revi, 2009). Therefore International scholars are now noting two significant changes in the climate change discourse in India: 1) There is a shift in the position of the government in international and domestic forums on India's responsibility to reduce emissions by efforts such as constituting a Council on Climate Change and mandated eight national missions to address energy security among other vulnerabilities as part of Nation Action Plan on Climate Change (NAPCC 2008) (Thaker and Leiserowitz, 2014). 2) The current climate change discourse in India is trickling down from the elite group of scholars, NGOs and foreign policy experts to government bodies and policy makers in the Centre, state and city level.

2.2.3 The policy context: Indian planning policy process

The Central, State and Local governments are responsible for preparing and implementing various policies pertaining to poverty reduction, population control, providing and improving socio-economic facilities and environmental protection across India. In India, the Central Government lays down policies and priorities of development work with the help of the Planning Commission (Policy preparation institution of the Government of India) and allocates central funds to states for various developmental activities (Commission, 2008, 2011). Then the State and Local government prepare development plans for various developmental activities under the purview of 73rd and 74th Amendments of the Indian Constitution (Ansari, 2004). There are two types of plans that are prepared by local governments: spatial plans and city development plans. In India, spatial plans are referred to comprehensive, cross-sectoral, co-ordinating spatially oriented planning in the public sector. These are long-term policy plans (20-25 years) focussing on spatial-economic development for settlements and cities and it optimise the spatial distribution of land uses. Whereas the City development plans are short-term plan (7 years) aimed at encouraging reforms for fast track planned development of urban infrastructure, service delivery mechanisms and community participation in the cities. Policy documents differ in terms of content and approach. Spatial plans have a legal support and guides development of cities through regulatory framework such as bylaws and standards for various activities. City development plans on the other hand are seen as a priority action plans for various infrastructure activities and instrument to finance these activities.

In India, historical evidence of spatial planning dates back to the first intensively developed settlements of early civilizations, known as the Indus Valley Civilisation (Khan and Lemmen, 2013). It was well-planned space with organic growth. The modern planning practices emerged after the European Industrial Revolution. Since then spatial planning practices have been changing with problems emerging from rapid urbanization. Modern planning practices in India find its roots in the British rule in the Indian subcontinent between 1858 and 1947 (Mukherjee, 2011). They initiated basic planning practices to seek and protect health and well-being. Under the basic planning provision, they developed sewerage, control of sprawl, location of industry and the creation of pleasing aesthetic spaces. Recently, policy maker have included environmental protection, public participation and the imperative sustainable development into the spatial planning practices. Current planning practices are influenced by concepts form Europe, UK and USA, like Ebenezer Howard's Garden City concept, Patrick Geddes' concept of Survey-Analysis-Plan etc. The planning practice in India are changing gradually to add new layers of approaches and frameworks like Advocacy planning influenced from Neo-Marxist planners and neo liberal approaches derived from global and free market systems(Nath, 2007). Not all these new concepts and layers of approaches are integrated perfectly into the planning practices in

India. In the current state of social-ecological interaction due to internal and external forces becoming complex, challenges for the current spatial planning are addressing issues like multiple deprivation, sustainability, resource distribution and climate change etc.

2.3 Methods

2.3.1 Developing the review framework

Several authors have addressed the question of how climate change can be integrated into the various policy agendas by proposing different frameworks (Brooks et al., 2011; Lim et al., 2005; UNISDR, 2012; Urwin and Jordan, 2008). These frameworks have been widely used at different spatial scales by various international and national research organizations. Most of these assessment frameworks are outcome or sector oriented (Tang et al., 2010), and are used to understand the key gaps and issues related to the climate concerns into policies (Preston et al., 2011; Urwin and Jordan, 2008; Wilson, 2006). The experiences of these frameworks were adapted and used as a reference to develop the review framework for this study, which focuses on the process and potential outcome of spatial plans in future.

Preparing cities to the adverse impact of climate changes, local development authorities require capacity building for climate change adaptation (Moser and Luers, 2008). UKCIP (2003) and Moser and Luers (2008) broadly identify three main components to build adaptive capacity to cope with climate change issues, namely awareness, analysis and action (also known as the 3A's). This study adapted the core concept of UKCIP (2003) and Moser and Luers (2008) of the 3A's to understand the integration of climate change issues at local level in various cities in India. However, the usability of the 3A approach at various cities in India or other developing countries has its limitation. For example, in the case of India, most spatial plans are in different stages of application and potential impacts of various sectoral policies under spatial plans are unknown. It could be hard to apply 3A approach directly as it is unable to capture the essence of comprehensive development on climate change issues. Majority of cities in India are still struggling with basic issues like physical development, poverty and environment in general and ways to integrate climate change issues along with these basic issues is a big question. Using the 3A components to review spatial plans in India requires the development of a set of criteria under each component that reflect the range of activities that might be expected in the spatial plan and planning process. Thus, the framework defined earlier was adapted to synchronise with Indian spatial planning policies, to form the new review framework. To do this, a pilot analysis was conducted to identify various issues covered under each spatial plan in different cities in India. Results of the pilot analysis showed that the key areas dealt within the spatial plan are issues like awareness, participation, physical development, public services and socioeconomic problems.

Based on previous studies on climate change, we identified the main issues that should be represented in spatial plans and correlated them to the ones already mentioned in the pilot study (Baker, 2012; Brooks, 2011; Wilson, 2010; Adger, 2007; Füssel, 2007). The final selection of criteria from the literature and initial analysis of the spatial plans aided in adapting the review framework.

Identification of significant criteria in each component was a crucial step for this study to measure the ability of local authorities to address and plan for climate change issues. The majority of research study on climate change action response used multiple and complex variables to identify the impacts of climate change at various spatial scales (Neil Adger et al., 2005; Stern, 2006; UNISDR, 2012; Wilson and Piper, 2010). The criteria selected for this study from various climate change literature influence the geographic, political, social and economic settings of the region and are usually affected by many internal and external factors like decision-makers' values and experiences, information base, participation, technical exposure and awareness of alternatives. Forty criteria were identified for this study depending upon the spatial scale and relevance. 4, 15 and 21 criteria were selected under awareness, analysis and action component of the review framework (Table 2-2). The number of criteria varies across the entire three components because of their relevance and cross-interaction across all the three components. The majority of these criteria under each component were chosen due to their primary focus on adaptation to climate change in planning policy at local level and while targeting either a single sector or, more broadly, any organization that is undertaking adaptation.

The awareness component aims at assessing to what extent the plan shows an understanding of the key drivers of climate change and its impacts at the local level (Baker et al., 2012; Lindseth, 2004). For instance, it includes criteria related to awareness of levels of greenhouse gas emissions (GHG) and their impacts on climate variables. Majority of cities in India conducts a basic inventory of GHG, but awareness about the impacts of GHG is lacking. The analysis component looks at the extent to which the spatial plan shows a capacity to analyse, quantify and synthesize the available information on climate change in a useful form to support planning decisions (Baumert et al., 2005; Brooks et al., 2011). Although the spatial plans deals with the driving factor of climate change issues and key forces to build adaptive capacity locally, like building infrastructures, land use policy, resource distribution, social and physical structures, the lack of understanding of the basic issues results in inefficient adaptation policies. A better understanding of cross interaction and impact between various factors can help to develop efficient response action for climate change adaptation. Finally, the action component assesses if and how the spatial plan contains specific responses to cope with climate change. These responses may include for example regulations related to physical, social development, but also actions aimed at reducing the vulnerability of the population (Biesbroek et al., 2010; Füssel, 2007; Tompkins et al., 2010).

Table 2-2: The review framework developed for this study.

Component	Criteria	References
Awareness	Concept of climate change or global warming	(Jabareen, 2013, Tang et al., 2010, Parry, 2007)
	Prediction of the impacts of climate change on the biophysical/social/economic context of the planning area	(Hallegatte et al., 2011, Füssel, 2007, S. Agrawala, 2009)
	Long term goals and targets for changing climate variability and its impacts	(Hallegatte et al., 2011, S. Agrawala, 2009, Neil Adger et al., 2005)
	Guidance and standards for the implementation of adaptation and mitigation measures in planning area	(Hurlimann and March, 2012, Carter, 2011, Hallegatte et al., 2011)
Analysis	Base year assessment of GHG emission	(Hoornweg et al., 2011, Baumert et al., 2005)
	Categorization of GHG emission type and source	(Dodman, 2009, Baumert et al., 2005)
	Future emission trends forecast	(Hoornweg et al., 2011)
	GHG emission scenario development	(Hoornweg et al., 2011, Moss et al., 2010)
	Assessment of the physical development	(Handmer, 2012, Habitat, 2011)
	Assessment of the transportation system in relation to climate change issues	(Habitat, 2011, Koetse and Rietveld, 2009)
	Assessment of water and sanitation situation in relation to climate condition issues	(Handmer, 2012, Biesbroek et al., 2010, Bogner, 2007)
	Assessment of energy demand and supply	(Mitigation, 2011, R.E.H. Sims, 2007)
	Assessment of land use change in relation to climate change.	(Ostle et al., 2009, Rounsevell and Reay, 2009)
	Assessment of the consequence of the changing climate on natural and protected area.	(Naumann et al., 2010, Heller and Zavaleta, 2009)
	Assessment of the consequence of the changing climate poverty distribution pattern	(Habitat, 2011, Eriksen et al., 2007)
	Displacement and forced migration cause of changing climate variables	(Raleigh et al., 2008)
	Assessment of the employment and livelihood structure	(Barnett and Adger, 2007)
	Assessment of the sectoral economy of the planning area	(Bernstein, 2007)
	Cost estimation of the physical asset disaster	(Stern, 2006, Agency, 2012, Weitzman, 2009, Heltberg et al., 2009)
	Cost estimation for GHG emission reduction	(Stern, 2006)
	Assessment of the organization and political support to have the capacity to act on climate change issues	(Urwin and Jordan, 2008, Lim et al., 2005)
	Engagement of relevant stakeholders	(Held and Hervey, 2011a, Lim et al., 2005)
	Definition of roles and responsibilities	(Held and Hervey, 2011b,

		Corfee-Morlot et al., 2009a)
	Exploitation of synergies with other climate change policies	(Held and Hervey, 2011a, Corfee-Morlot et al., 2009a)
Action	Disaster-resistant land use and building code	(Habitat, 2011, Tang et al., 2010, Hallegatte, 2009)
	Conservation of parks, forest and natural and protected area	(Naumann et al., 2010)
	Infill development and reuse of remediated brown field sites	(Habitat, 2011, Tang et al., 2010)
	Green building and green infrastructure standards.	(Tang et al., 2010, Hallegatte, 2009)
	Low-impact design for impervious surface	(Tang et al., 2010, Grimm et al., 2008)
	Pedestrian and bicycle-friendly, transit-oriented community design	(Tang et al., 2010, Kahn Ribeiro, 2007)
	Multimodal transportation strategies	(Kahn Ribeiro, 2007)
	Climate proofing of transport infrastructure	(Habitat, 2011, Kahn Ribeiro, 2007)
	Renewable energy and solar energy	(Tang et al., 2010, Rice, 2007, R.E.H. Sims, 2007)
	Energy efficiency and energy stars	(Tang et al., 2010, Rice, 2007, R.E.H. Sims, 2007)
	Waste management and GHG mitigation technologies	(Bogner et al., 2008, Dechezleprêtre et al., 2008)
	Waste water control and treatment	(Semadeni-Davies et al., 2008)
	Policies to provide health facilities , insurance , food security and education	(Eriksen et al., 2007, Sperling, 2003, McGuigan et al., 2002)
	Financial / budget commitment	(Neil Adger et al., 2005, McGuigan et al., 2002)
	Identify role and responsibility among sectors and stakeholders	(Held and Hervey, 2011b, Corfee-Morlot et al., 2009b, Neil Adger et al., 2005)
	Public awareness and education about the climate change issues	(Corfee-Morlot et al., 2009b, Neil Adger et al., 2005)

2.3.2 Scoring spatial plans against the evaluation criteria

These 3A components, each with sub criteria, provide a framework to review climate change integration across various spatial plans. In order to give a quantitative score to each criterion in the review framework, a set of rules was developed (appendix 1).

The evaluation of the individual spatial plan was conducted by scoring them against a criterion on a three-point scale (0, 1 or 2) following the analytical approach of previous studies on plan quality (Baker et al., 2012; Preston et al., 2011; Tang et al., 2010). The criterion was given a score 0 if there was no evidence of the criterion throughout the spatial plan. A score of 1 was given if the criterion was acknowledged in the spatial plan, but lacked further details. Lastly, a score of 2 was given if the criterion was acknowledged and significant information and analysis was addressed in the spatial plan. The specific requirements associated with each possible score varied among different criterion, but generally followed a consistent system. The assigned scores were cross checked twice across the range of criterion for robustness.

The scoring system is best illustrated with an example. Considering the criterion 'Base year assessment of GHG emission', a particular spatial plan is to receive a score of 0 if GHG emission is completely overlooked in spatial plans. Spatial plans to receive score 1 if the spatial plan has briefly mentioned about the overall picture of the GHG emission for the base year but no further information provided in the spatial plan. For a score of 2, the criteria have to provide the details on the amount of GHG emission and significant information about the sources of the emission within the spatial plan.

2.3.3 Selection of the sample of spatial plans

The selection of spatial plans was based upon few independent variables like population, special character of the region, capacity of the urban local body and availability of these documents in the public domain in India prior to 1 February 2013. During the selection of the spatial plan, first 54 cities from 24 states and 4 urban territories of India were identified as per the 1 million population criteria. After considering other criteria like special characters of the cities, financial capacity, risk /stress variable and finally accessibility of spatial plans and policies to the public, 46 cities were selected across India. Some of these cities have two categories of planning policies as mentioned in chapter 1.

This study considered both categories of policy documents, the first being spatial plans and the second city development plans. Of all the spatial plans available in the public domain at the time of study, the selected spatial plans were a convenience sample based on access to these documents, while new spatial plans continue to emerge. The selected spatial plans represent a broad range of geopolitical situations from various cities in India; include samples of traditional planning policies like master plans and new generation plans like city development plans (Figure 2-2). They have been prepared by local governments or under the governmental vision framework. Some spatial plans were developed by a single organization while others were prepared through cross-governmental working groups or committee (appendix 2).

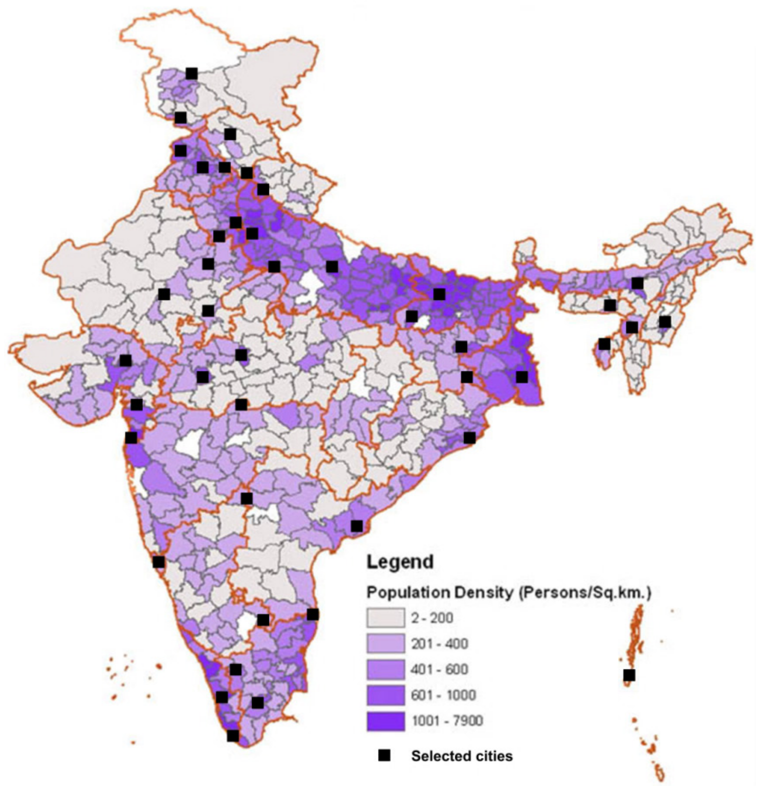

Figure 2-2: The population density map of India showing selected cities for which spatial plans were evaluated.

2.3.4 Data analysis

The data analysis was conducted in three stages. In the first stage, the overall performance of the 59 spatial plans against 40 criteria was examined based upon the sum of the original scores (no standardization) for review framework. The second stage looked into the extent of integration of different components of climate change (awareness, analysis and action) into spatial plans. The sum of the original scores for each component was standardized on a 0-1 scale. Descriptive statistics was then used to assess the performance and interrelationship among the components. In the third stage, the performance of each criterion in all the spatial plans was evaluated using the performance analysis. The criterion performance analysis was performed based upon the work of Tang et al., (2010) on the depth and breadth scores in the climate change action plans. His depth and breadth percentage score analysis was an appropriate method to analyse the criterion performance on both aspects of relevance and extent of involvement in spatial plans that was not possible with the descriptive statistical analysis. The depth percentage score measures how much importance is given for each criterion in the spatial plan meaning how a criterion was addressed in the spatial plan (Equation 1). Whereas breadth analysis was used to measure the extent to which each criteria were addressed across all the spatial plans (Equation 2).

$$\text{Breadth score(BS)}_{\,j} = (P_j/N) * 100 \quad (1)$$

$$\text{Depth score(DS)}_{\,j} = (\sum_{j=1}^{P_j} I_j/2P_j) * 100 \quad (2)$$

Equation (1) and (2) represent the criterion breadth score and a depth score of j^{th} criterion on the scale of 0-100 % and where, P_j is number of plans that address the j^{th} indicator. N is the total number of spatial plans in the study and I_j is the j^{th} indicator receiving scores on the scale of 0-2.

2.4 Results

2.4.1 Overall performance of spatial plans

Consistent with the evaluation framework adopted, the overall performance of the spatial plans is expressed by a score in the 0-80 range. This is because each criterion can have a maximum score of 2 and for 40 criteria; each spatial plan can have a maximum score of 80. Figure 2-3 show that none of the spatial plan provides comprehensive coverage of all the criteria under each component. It was observed that across all the evaluated spatial plans only 5.1% of the spatial plans ranged between 41-60 (50-75%), 76.3% of spatial plans between 21-40 (26-50%) and 18.6% of spatial plans fall under 1-20 (below 25%) score range. None of the spatial plan scored above 60 (above 75%). According to the descriptive statistics (Figure 2-3), the total mean score for overall performance of the spatial plans is 26.88 which is 33.5% of the total possible score on a scale of 0-80. The maximum and minimum score for a spatial plan was 50 (62%) and 14 (17.5%).

2.4.2 Performance by components

As shown in Table 2-3, the mean score for the awareness component was 0.09, analysis component was 0.23 and action component was 0.20. Figure 2-4 shows that only few spatial plans have significant awareness about climate change issues (about 3% of spatial plans) and only 10% of the spatial plans have relevant analysis and action strategies on climate change issues. 75% of the spatial plans do not demonstrate awareness, analysis and action response related to climate change issues in various cities of India. Table 2-3 reveals that the awareness towards climate change policies was considerably low across all spatial plans. An analysis component of the review framework performed better than action and awareness components during the assessment of spatial plans. In addition to this, Table 2-4 shows the correlation amongst the three components and indicates that the relationship between analysis and action components are significantly correlated ($p< 0.01$).

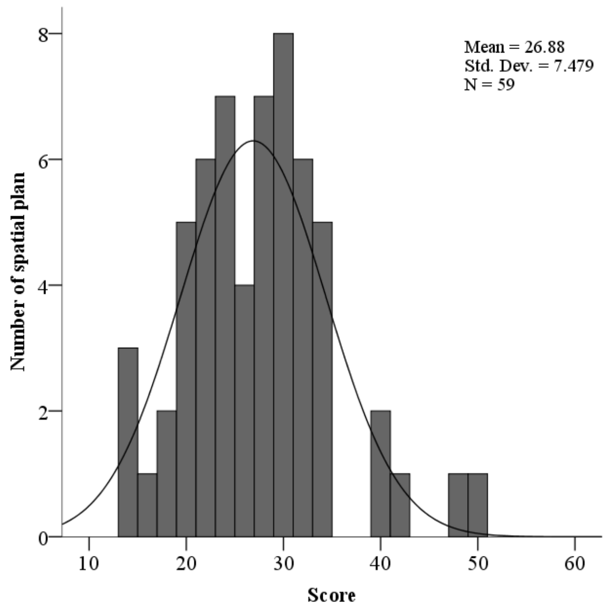

Figure 2-3: Frequency distribution of evaluation scores for individual spatial plan.

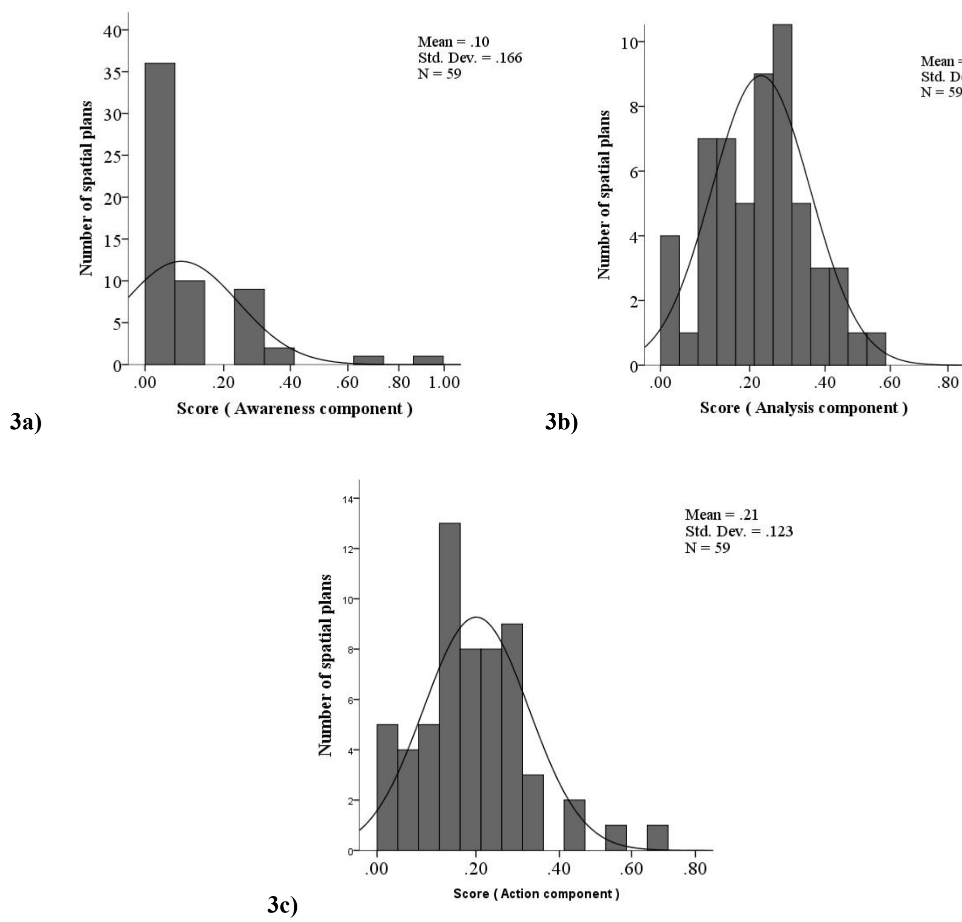

Figure 2-4: Performance of spatial plans by components, 3a) Awareness components, 3b) Analysis component and 3c) Action component.

Table 2-3: Descriptive statistics of overall performance and various components across all spatial plans.

Variables	Awareness	Analysis	Action
Mean	0.09	0.23	0.20
Std. Deviation	0.16	0.12	0.12
Minimum	0.00	0.00	0.04
Maximum	0.88	0.55	0.65

Notes: The maximum score for each component of awareness, analysis and action is 1 and minimum 0 (after standardization).

Table 2-4: Correlation matrix for the three components of climate change issue.

Component	Awareness	Analysis	Action
Awareness	1		
Analysis	.321*	1	
Action	.417**	.758**	1

** Significance at the 0.01 level (2-tailed).

2.4.3 Performance by the criterion under each component

2.4.3.1 Criteria performance of awareness components in spatial plans

It is evident from Figure 2-4 that few cities recognized the need to have long term goals to deal with the climate change issues. These include the awareness related to prediction of impacts of climate change on biophysical, social and economic spheres (23.7% breadth and 57.1% depth) and long term goals and impact of changing climate variables (23.7% breadth and 53.6% depth). Awareness about climate change issues is essentially the fundamental and foremost steps that need to be integrated into spatial plans and other sectoral policies. According to Tang et al., (2010) "the low awareness about climate change issues in the policies are among the main reason of under performance of analysis and action components". The relative depth score of the awareness component indicates that only few spatial plans included the different awareness criteria and most of them show low depth score when it comes to the awareness at local scales.

2.4.3.2 Criteria performance for analysis components in spatial plans

Majority of the spatial plans had conducted a moderate level of analysis for physical development, environment, and economics, social and organizational aspects of the broader level in the planning region. For example, this study indicates that all spatial plans conduct physical assessment of the planning region, assessment of the transportation system, water, sanitation and economic condition in cities and most of them have reasonable depth details. However, it was observed that the majority of these plans did not consider criteria such as cost estimation for GHG emission reduction and future emission trend forecasts. Less than 10% of the spatial plans consider GHG emission scenario and cost estimation of the physical asset disaster. Figure 2-6 shows the breadth and depth scores for various criteria under the analysis component of climate change issues from sample of cities in India.

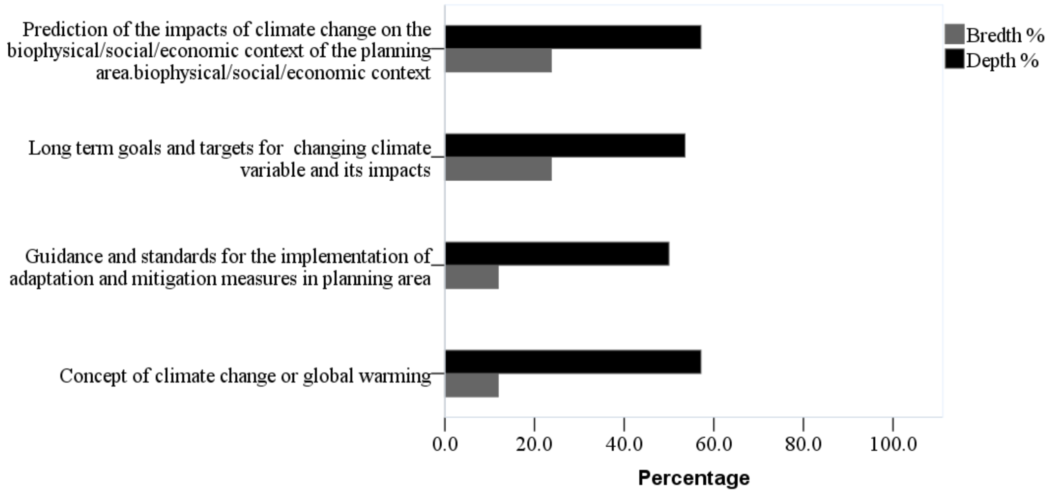

Figure 2-5: Criteria performance of awareness component of spatial plans.

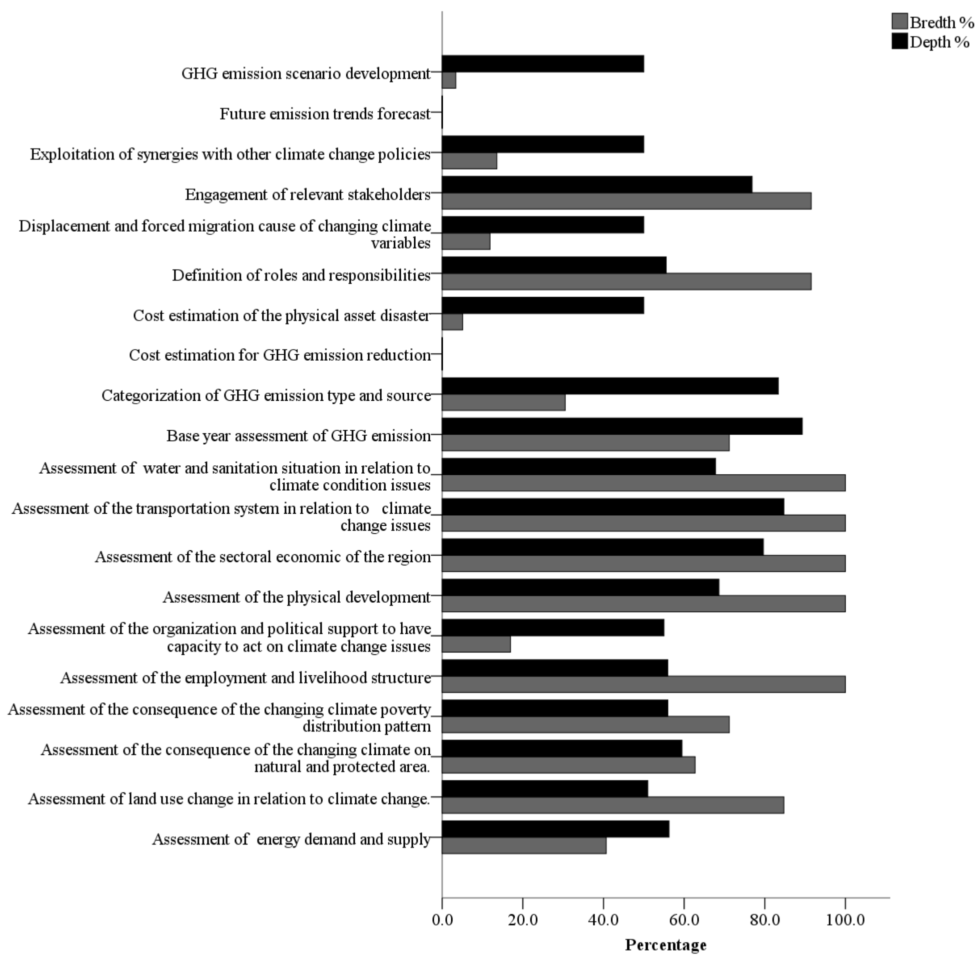

Figure 2-6: Criteria performance of analysis component of spatial plans.

2.4.3.3 Criteria performance of action components in spatial plans

The action component includes a combination of policies, tools and action responses. Some of the criteria under the action component of climate change were well covered under the spatial plans, for instance action response under physical development, transport infrastructure development and public amenities. Other criteria like response actions under energy, green infrastructure and environment were not given due importance in most spatial plans. Breadth and depth score of various criteria under the action component are shown in Figure 2-7.

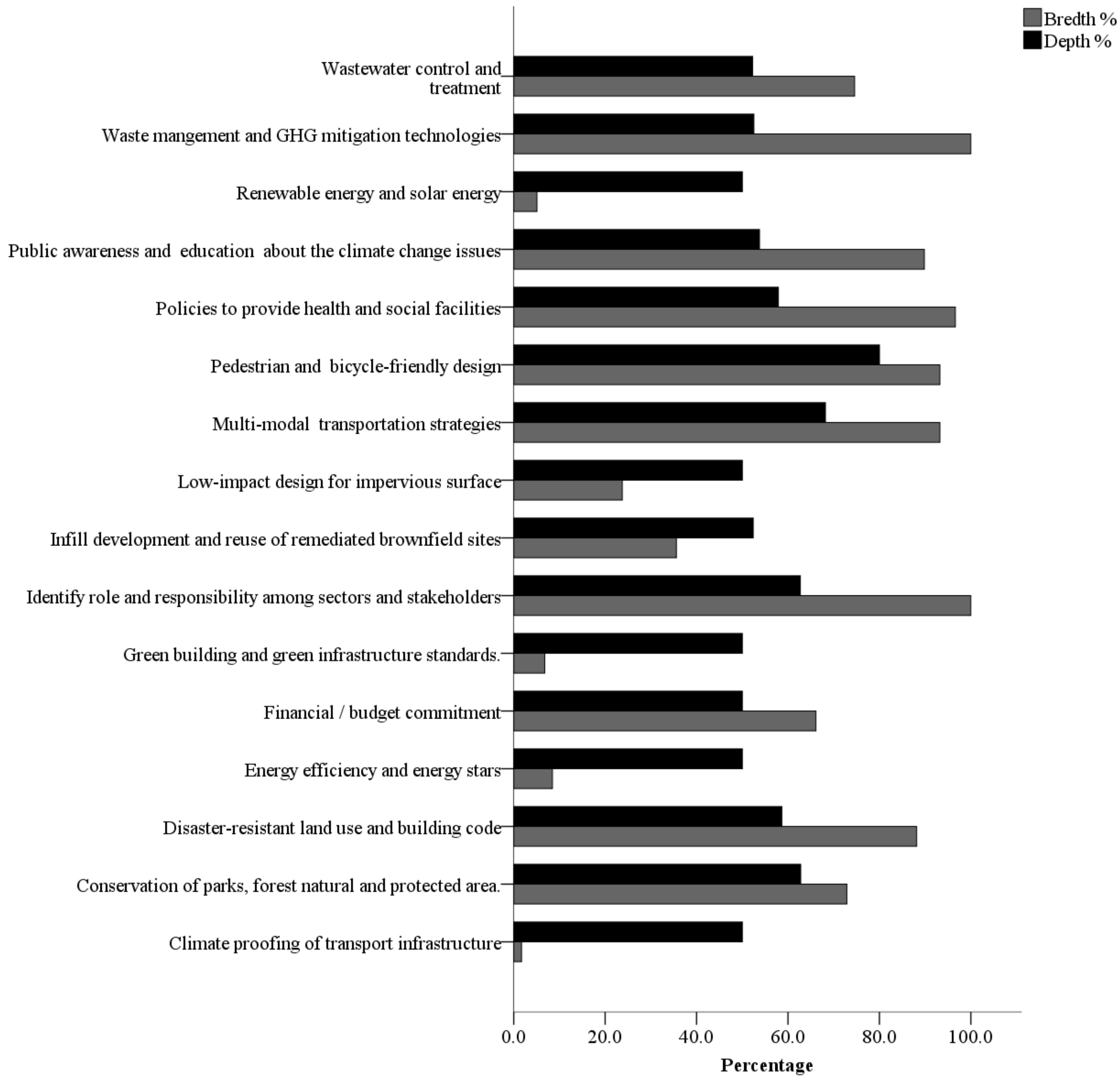

Figure 2-7: Criteria performance of action component of spatial plans.

2.4.4 Performance of cities across India

The performance of a city was rated according to how well each of the components (awareness, analysis and action) was reflected within in each sampled spatial plan. It was found that majority of cities in India are not yet ready for climate change issues at the policy level. About 70 % cities out of 46 sample cities performed poorly on integrating climate change issues into spatial policies examples of these cities like Kota, Jodhpur, Haridwar and Coimbatore etc. About 26% cities performed below average on overall performance. Although some of these cities indirectly analysed a few issues related to climate change, lack of awareness on the theory of climate change affected their performance at the level of undertaking action. 4% of the cities performed above average on integrating climate change issues into spatial plans. These cities like, Delhi, Port Blaire, Kochi etc., also provided comprehensive coverage of all the three-component of awareness, analysis and action. The results of the study show that majority of spatial plans across sampled cities in India have failed to identify climate change issues and avenues for implementation (appendix 3).

2.5 Discussion

Integrating climate change issues into spatial plans can be a judicious step to reduce climate change vulnerability and increasing resilience of cities in India. Developed nations have made it mandatory to integrate climate change issues in their general policy agenda whereas developing countries are still struggling to see climate change as an issue to integrate into their established policies (Berrang-Ford et al., 2011; Gagnon-Lebrun and Agrawala, 2007). A country such as India which is the second most populous country in the world and where 31.1% of the population reside in urban areas (covering only 2.34% of the land) is amongst the most vulnerable region in the world towards global climate change. For example, in 2005 Mumbai was struck by a cyclone and high intensity rain for 24 hours (De Sherbinin, 2007). It affected thousands of people in the city, disrupting the physical infrastructure, business and daily activities for a few weeks. About 1,000 people died in slums and vulnerable physical condition. Incident likes these forced national and state governments in India to initiate a few policies at various spatial scales to deal with climate change issues, but the majority of them were sectoral oriented policies (Commission, 2011).

However, the review of 59 spatial plans across 46 cities in India highlighted the fact that the role of spatial plans at the city level is still limited. During the study, it was seen that different expert groups / task units developed different aspects covered under spatial plans and they fail to connect and to consider the impacts of strategies across different sectors. Some of these examples can be identified from the majorities of spatial plans like a land use and environmental policy is often in conflict with other policies, such as economic, transport and physical development policies etc.
The study also showed that the overall performance of spatial plans to integrate climate change

issues varies across cities. There are many potential reasons why and how different cities in India have a different performance score to integrating climate change issues into spatial plans. This study shows that lack of awareness, participation, technical skill and action response are the prime reasons for the weak performance of spatial plans. These reasons are strongly correlated with the performance of the spatial plans in integrating climate change issues amongst various cities in India. Cities such as Delhi, Kochi, Mumbai and Port Blair demonstrated an established integration of climate change issues into their spatial planning process. It was also observed that these are also among the cities that face regular climate change issues and have been preparing themselves for the same. However there are many other cities in India, that are under regular threat of climate change issues but do not have any kind of safeguard in their local policies. Cities like Coimbatore, Vishakhapatnam, Panji, Imphal, Aizawal, Gurgoan and Hyderabad etc., are located in extremely delicate environmentally prone regions.

A crucial issue identified during the evaluation of spatial plans was the lack of awareness about the climate change issues amongst various stakeholders and their participation in it. Public participation and awareness are vital aspects of effective climate change policy preparation and implementation (Smit and Wandel, 2006). Awareness about the climate change issues can be a driving force to local governments and people to build trust and commit themselves to act on the relevant action response (Hjerpe and Glaas, 2012; Tompkins et al., 2010; Neil Adger et al., 2005). However, environmental and climate change issues were given the least priority in majority of the sampled spatial plans. Equipped with the strength of media and social networking, state and local governments in India could have promoted the impacts of past and current events of changing climate variability.

The other major issue after awareness was the moderate level of analytical capability of local governments to see climate change as an issue and its impacts. Few urban bodies like Delhi, Mumbai and Kochi have analysed the impact of climate change and have been able to integrate climate change aspects in the spatial plans. At the same time, these cities have the resource capacity in term of technical skills, physical resources, financial capability and involvement of various stakeholders to act on various climate change issues. Most cities in India have been seen to follow a mix of chaotic growth development, which leads to inefficient management of resources (Nath, 2007). Sampled cities for this study are extremely populated as well as being most vulnerable to climate change impacts and have already experienced disaster like flooding, Tsunami, sea level rise and changes in seasonal patterns etc. in the past.

Local government and policy makers have made physical development and economic growth prosperity as the basis to formulate policies in various cities in India (Nath, 2007). The focus of most spatial plans is primarily in a few key sectors such as physical development (built environment, transportation, water infrastructure and industrial development etc.) and socioeconomic well-being. This approach overlooks the issues related to environmental prone impacts to society, human well-being and sustainability of the region as a whole. The roots of such neglect can be easily identified as limited resources and potential to see the future uncertainties related to climate change issues.

The other major issue identified was related to action responses included in the spatial plans. Action responses in the sampled spatial plans predominately focus on land use change policies, build environment and few environmental norms. Whereas the city development plans sampled for this study revealed the focus on building local economy, public infrastructure, and poverty alleviation without considering global climate change. Although local governments have made relevant policies on these issues, which are amongst the main drivers of climate change vulnerability, they are not moulded to into instruments to reduce the climate change impact and vulnerability. An innovative integration of climate change issues in projected action under various spatial plans could have a significant influence in dealing with climate change impacts. For example, strategies like green infrastructure and energy efficiency in physical development, climate proofing of long lasting infrastructure like transport system in the cities, accounting of GHG emission from various sectors, carbon taxing on heavy industries etc. can be easily improvised into current action responses (Agency, 2012b; Carter, 2011; Habitat, 2011; Corfee-Morlot et al., 2009).

73rd and 74th Amendments of the Indian Constitution vests enormous power with the Local governments to plan and implement action responses. Therefore, these local governments can plan for sustainable development of the cities to become resilient towards various impacts of climate change. Various studies show that local governments around the world are introducing policies like green infrastructure, carbon taxing, local GHG emission inventories and scenario development and ecosystem based adaptation policies at various spatial scales (Biesbroek et al., 2010; Field et al., 2012; Naumann et al., 2010). Local governments and policy maker in India can learn from such initiatives and adopt innovative policies which best fit into their local environment. Recently many international and national organizations initiated climate change mitigation and adaptation learning programs like Global Environment Fund (GEF) Trust Fund , Strategic Priority on Adaptation (SPA), Special Climate Change Fund (SCCF), Adaptation Fund and Least developed countries fund (LDC Fund) under which any local government across developing world can participate to reduce the climate change vulnerability (Mace, 2005). Local authorities in various cities in India can take advantage of these policies and become part of the learning program.

The study of sampled spatial plans from various cities in India presented opportunities to learn about the policy changes taking place and gaps in the Indian public policy arena. The developed review framework is a robust instrument to understand the stance of various cities in India and its spatial policies on climate change issues. The review framework was able to reveal key weaknesses and strength of spatial plans on integrating climate change issues. The review framework could be applied to another region by adjusting the criteria that suites the need and context of the region while keeping the main skeleton of review framework. The selected criteria and weight for this study were based upon the spatial policies of India and information available under spatial plans that are universal across India.

Chapter 3

3 Introduction to the case studies

3.1 Bangalore city profile

3.1.1 Introduction

The historical accounts of the city of Bangalore indicate that it was a small agrarian village in the 12th century AD (Sudhira and Nagendra, 2013). The strategic location of this small village and the all year favourable climate was recognized by Kempe Gowde, a descendent of the Yalanhanka line of chiefs, in 1537, who constructed four pillars indicating the boundaries for potential growth in the heart of present day Bangalore (Sudhira and Nagendra, 2013). The City has now expanded well beyond these anticipated limits into the 5th largest metropolitan city in India. It is one of the fastest growing cities of the world with a tag of the 'Silicon valley of India', for spearheading the Information Technology based industries in the country. Bangalore has placed itself in the global Information Technology map with The Human development report 2001 (UNDP, 2001) placing it in the 4th place in terms of the most advanced technological hubs of the world, attaining a high Technological achievement index (TAI) of 13 (Lema and Hesbjerg, 2003) . However the same report also states that "Development and Technology shares an uneasy relationship", to highlight the new risks that inevitably accompany technological growth. The economic development of the city due to its technological hub has resulted in rapid growth in population mainly owing to migration, simultaneous urban sprawl, deteriorating impact on the cities ecosystem, encroachment on green spaces, pollution of lakes and felling of trees to make way for urban infrastructure. In addition to these inherent problems, like most developed and developing cities, it is likely that the city will be further exasperated by the effects of climate change (Rosenzweig et al., 2010). The importance of tackling climate change at the city level was recognized at the World Mayors Council on Climate Change (WMCCC) in December 2005, following its entry into force of the Kyoto Protocol (Rosenzweig et al., 2010). It was recognized that compared to national politicians, city leaders and governing bodies have a better understanding and willingness to take action against the changing effects of climate change. Thus Bangalore represents an ideal case study to initiate an in-depth study on the potential vulnerability of an urban city to climate change and how to initiate effective policies to combat such changes. This chapter thus details the profile of the city, which provides a base for understanding the spatial assessment of vulnerability of Bangalore city as detailed in chapter 4.

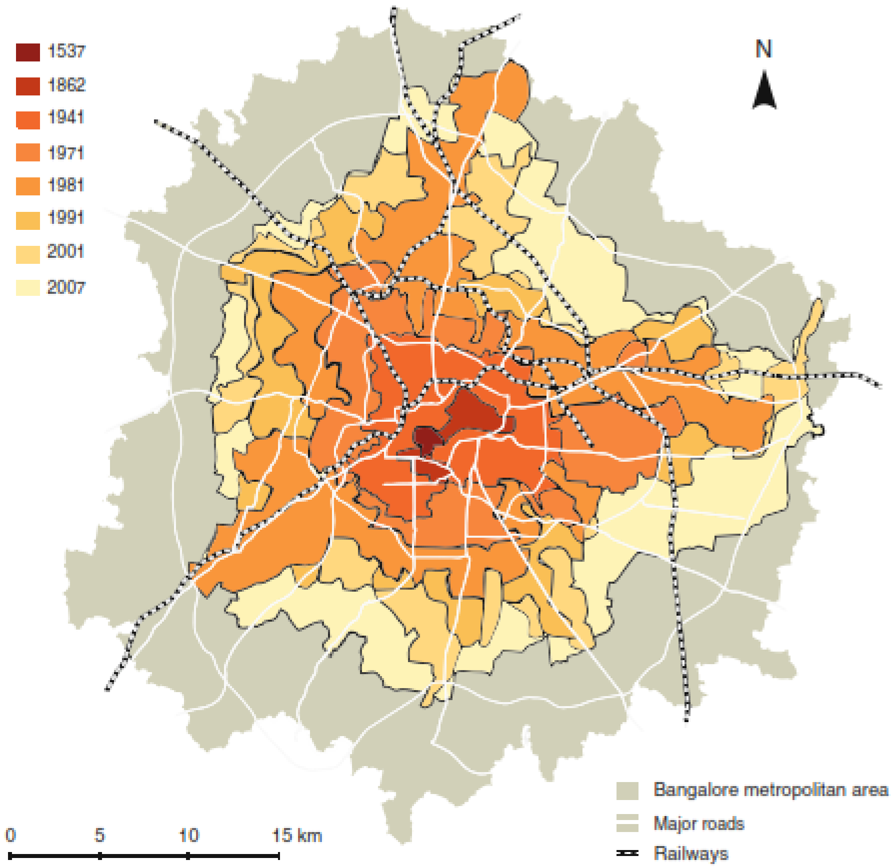

Figure 3-1: Growth of Bangalore from 1537 to 2007 (*Source: Adapted from H.S Sudhira and H. Nagendra (2013)*)

3.1.2 Geography

Bangalore is the principle administrative capital of the State of Karnataka, and lies equidistant from the eastern and western coasts of Southern peninsula of India. Geographically it is located between latitudes of 12^{o} 39' N and 13^{o} 18' N and longitudes of 77^{o} 22' E and 77^{o} 52' E and covers an area of 741 km^2. It is situated in the middle of the Mysore plateau with an average elevation between 700 to 900 m over the ridges of four watersheds namely, Hebbal, Koramangala, Challaghatta and Vrishabhavathi. The terrain being undulating was suitable for creation of tanks to provide water for drinking, irrigation and fishing. Once abundant with these water bodies, with as many as 262 even in 1961, high real estate prices has resulted in the fast decline of the lakes. Although the official figures still state that the number of tanks is 171, most of these are only seasonal and remote sensing images clearly indicate only 33 existing lakes with another 15 only showing contours of former existence. Rapid growth including congested roads networks and residential centres has also reduced the green spaces in the city and number of trees in the city. Two prominent green spaces, the Lalbagh and Cubbon Park, are located right in the centre of the city.

Table 3-1: Changes in number of water bodies during 1973 to 2007

Year/ region	Bangalore City		Greater Bangalore	
	Number of Water bodies	Area (in ha)	Number of Water bodies	Area (in ha)
SOI	58	406	207	2342
1973	51	321	159	2003
1992	38	207	147	1582
2002	25	135	107	1083
2007	17	87	93	918

Source: Adapted from (Ramachandra and Mujumdar, 2009)

3.1.3 Demography and economy

Bangalore is the capital of the state of Karnataka with Kannada as the official language. The city has a high literacy rate of 75% (Census of India, 2011), of a population of 5.7 million people. About one third of the populations according to the last census are migrants from the neighbouring rural areas and other states. The significant increase in the population of the city in the 1970's was a result of establishment of numerous public sector and defence establishments. Subsequently there was increase in population during the 1990's due to immigration for the IT industries. Apart from the cities well developed IT hub, it also nurtures several educational and research centers such as the Indian Institute of Science (IISc), National Institute of Advanced Studies (NIAS), Tata Institute for Fundamental Research (TIFR), Jawaharlal Nehru Centre for Advanced Scientific Research (JNCASR), Indian Space Research Organisation (ISRO), National Aerospace Laboratories (NAL), Defence Research and Development Organisation (DRDO), Indian Institute of Management (IIM), Institute for Social and Economic Change (ISEC), Indian Institute of Information Technology (IIIT) and several professional engineering and medical colleges. Bangalore's economic growth although attributed to its Information and communication technology (ICT), is highly diverse with industries likes textile, automobile, machine tools, aviation, space, defence and biotechnology constituting its economic fabric. Although the city boasts a high per capita income of Rs 39,420, socio-economic inequality remains high with 25 % of the population under the prevailing poverty limits (Census of India, 2011)

3.1.4 Urbanization and Environmental Issues

The change in the economic, social and demographic fabric of the city in the last three decades has resulted in a drastic transformation in the landscape of the city. The cities once rich historic parks, open spaces and large water bodies have been encroached upon to give way to infrastructural development, housing areas and commercial establishments. With minimal governance in the spatial development of the city, the urbanization has been mostly irregular, spreading to the periphery of the city, accelerating landscape fragmentation in these areas (Schneider and Woodcock, 2008; Taubenböck et al., 2009). High prices of property in the city centre have resulted in minimum urbanization in the core and new developments being located in the peripheral areas of the city resulting in the modification of the ecosystems in the agricultural hinterland. The core of the city therefore still supports large green spaces managed by individual public institutions such as military campuses, educational institutes and historic cemeteries. There has been re-greening efforts in the periphery of the city in the form of avenue plantations, but the species used for such efforts have short life spans, low canopy cover and are water hungry exotic species such as *Acacia* and *Eucalyptus*. The loss of vegetation and lakes in the city of Bangalore is likely to intensify periods of droughts as well as flooding in the city. The rapid urbanization of the city also poses challenges in the water dynamics. Within the city, the piped water supply is sourced from at least a distance of 100 km resulting in high costs payable to energy usage for pumping of water. The high costs of piped water and inadequate availability in some areas of the city has resulted in the use of ground water via bore-wells and supplied by private tankers. The impervious urban infrastructure and soaring water demands has considerably reduced the levels of ground water. Another major problem due to rapid urbanization and increase in the working class population has been the multiplication of the vehicular pollution. According to the Regional Transport Authority 2012, the number of number of vehicles accounted for mounts to 3.8 million, mostly due to lack of proper public transport. It has been predicted that the total emissions of Co_2 for 2012 to 2017 will amount to 3.03 to 4.06 MT (Greenhouse Gas inventory Karnataka 2007). Initiatives are being taken to improve public transport by construction of a network of metro lines and cycling lanes, but such initiatives have been slow and not effective to the pressing problems of increase in vehicular population.

3.1.5 Governance and planning in Bangalore

The city level governance of Bangalore and its peripheral areas is theoretically in the hands of the Greater Bangalore City Corporation (Bruhat Bengalooru Mahanagara Palike), a body of locally elected representatives. However much of the planning such as land use zoning, housing initiatives and regulations are decided by a separate body established by the state government called the Bangalore development authority. Other sectors such as water supply, energy and law and order are also administered by state run organizations instead of the locally elected corporation. The result is that different organizations have administrative rights over different sectors as well as geographical areas leading to decentralized and chaotic governance. The main environmental management and data collecting bodies in the city are the Karnataka State Pollution Control Board (KSPCB) and the Lake Development authority (LDA). The KSPCB monitors the several forms of pollution including air pollution, noise pollution, hazardous waste disposal, solid waste management and also micro manage projects in the region by evaluating Environmental Impact Assessment notifications. The LDA on the other hand is specifically dedicated to the management of lakes and water bodies. Apart from these governing bodies, civil societies and community participation plays a vibrant role in the urban developmental issues in Bangalore.

3.2 Second Case Study: Darjeeling district profile

3.2.1 Introduction

If one needs unquestionable empirical evidence of climate change, the Himalayan region seem to be one the best case studies. Numerous scientific studies are now confirming that the effects of climate change are having rapid and confounding effects on the biodiversity, ecosystem services and human well being (Chaudhary and Bawa, 2011). With an aim to assess our methods in the Himalayan context, we chose the district Darjeeling situated in the lower Himalayas as a case study, which has seen rapid urbanization and land use change in the last century. This area was first recognized for development in the 19th century when the British administration set up a sanatorium and a military depot (WBGov, 2012). Since then the region has seen immense development due to extensive tea plantation in the region. Darjeeling tea known worldwide for its unique flavour, completely changed the revenue pattern in the district with the socio economic condition of the people largely being dependent tea plantation (WBGov). The region is also known for its beautiful hill stations and the unique Darjeeling narrow gauge railway line which is listed as a world heritage site.

Table 3-2: Darjeeling district general information.

Variables	Darjeeling
Area	3,149 Square km
Location	26˚31′ N to 27˚13′N Lat and 87˚59′ E to 88˚53′E Long
Altitude	200 m to more than 2,000 m above sea level
Density	584 persons per square km
Literacy	79.92%
Temperature	1˚ C to 11˚C with a maximum of 20˚C
Rainfall	Average annual rainfall ranging from 2500 mm to 3500 mm

Source: Darjeeling District profile (on http://darjeeling.gov.in)

3.2.2 Geography

Darjeeling is the northern most districts in the state of West Bengal in India. The district has an undulating topology with the northern part comprising of the steep terrains and southern part of the district lying mostly in the plains. There are numerous streams and rivers that flow down from the hills into the valley following the contours of the upland ridges. Rivers originating from the region contribute toward making the state of West Bengal being a well watered state for agriculture. Sharing parts of its borders with Bhutan in the east and Nepal in the west, it also enjoys a strategic location in terms of international neighbours. The four most important cities in the district are Darjeeling, Kalimpong, Kurseong and Siliguri (O'Malley, 1989). The hills of Darjeeling district are part of the Lesser and Sub-Himalayan belts of Eastern Himalayas and comprised of recent rock formations that results in a large number of landslides (WBGov).

3.2.3 Climate

Darjeeling has Temperate climate, (Köppen *Cwb,* Suptropical Highland Climate) with heavy rains during the monsoon season (Sinha, 2013). Due to great variations in heights above sea level, the variation in temperature is huge. The annual mean maximum temperature is 15.98 °C while the mean minimum temperature is 8.9 °C. The region gets a high amount of rainfall from July to September due to the monsoon winds with an average of 126 days of rain in a year (WBGov, 2012).

Observed trends in climate in Darjeeling district

- The temperatures is the district has been observed to be rising especially in the Darjeeling hill area where in the last 100 years it has risen by 4˚C
- The rainfall in the district has become irregular in quantity and timing with the number of rainy days decreasing form 165-140 days to 155-35 days in the last few decades.
- Relative humidity has risen considerably
- The amount of sunshine has increased in the Terai hill region
- The amount of snowfall has also become erratic in the hills.
- The frequency of landslides and flash floods has increased

Source: Based on discussions with locals and findings of Dr. Subir Sarkar, Head, Deptt. of Geography, North Bengal University as published in the West Bengal State Action Plan for Climate Change.

3.2.4 Demography and economy

The population of the Darjeeling is about 1.8 million with 33 % living in the four largest cities (Datta, 2004). The racial mix of the district is distinct with a large proportion of the population of the district belonging to the Gorkha clans, followed by the Sherpas (mostly involved in mountaineering activities), Denzongpas (Bhutias), Tibetians (migrants from Tibet since the 1950’s) and the Adivasis (Tribals from Chotanagpur and Santhal Parganas). Although the official language of the state is Bengali, 50% of the population speaks Nepali (Mor, 2013; O'Malley, 1989; WBGov).

The Economy of the region is mostly driven by tourism and tea manufacturing (WBGov). The tourism industry is seasonal peaking in summers and autumn. The frequency of landslides during the monsoon seasons, drastically effects tourism. Tea manufacturing is therefore the predominant form of revenue in the region engaging about 50% of the population in its 78 tea Estates which produce Darjeeling tea as accredited by the Tea board of India. The total area under tea production is 17, 500 hectares and annually the production is averages 90 million kg of tea (Datta, 2004; WBGov). The Darjeeling Tea industry not only provides direct employment and salary benefits but also provides other benefits such as housing, education, statutory benefits, medical facilities etc.

In addition, 38% of the district is under forest cover which produces superior quality timber and NFTPS. Also the hydropower generated from the region contributes towards the energy supply in the state (WBGov, 2012).

3.2.5 Environmental issues

District Darjeeling and its fragile mountain ecosystem is suffering from the burgeoning population, high density of urban growth, increase in area under subsistence farming and livestock farming in the region (WBGov, 2012). These factors are putting unprecedented pressures on the forests of the district due to encroachments for fossil fuel, fodder etc. (WBGov, 2012). Dense and moderate dense forests are changing into open forests at a rapid rate. The high rainfall in the region also causes massive damages resulting from soil erosions and landslides that damage agricultural lands, infrastructure, housing and living spaces in general (Mor, 2013). In addition there is high runoff in these areas due to which very little water is stored to be available in the lean periods. Additionally the urbanization of the region is further exasperating the effects on these existing problems by putting pressure on available recourses such as water, housing and sanitation. Planned development in this region has been slow. Therefore random and rapid growth together with the effects of climate change is likely to cause some major concerns for planners in the future. These concerns are summarized in the table below.

Table 3-3: Climate Change concerns in Darjeeling district

Sector	Concerns
Water	• Concerns of water availability in lean period due to heavy run off • Heavier soil erosion and landslides with increased rainfall periods • Impact on hydropower due to melting glaciers • Adverse problems on human settlements with increase in frequency of rainfall • Damages due to extreme climate conditions like cyclones

Agriculture and horticulture	• Shifting of agriculture production centres to higher altitudes • Lower produce of Darjeeling tea as the climate creating its special aroma changes • Impact on horticulture produce such as the Darjeeling Mandarin • Increase in pests and diseases, and emergence of new ones
Biodiversity and forest	• Degradation of forests areas due to landslides population growth around forest areas • Species migration due to changing weather conditions • Adverse impact on natural population of orchids • Impact on forests and its biodiversity, NTFPs including medicinal plants • Frequency of forest fires during the dry season
Health and social structure	• Impacts on human health as vectors move to higher altitudes and people are • subjected to heat stress , which they have never encountered • Impact on low income housing with increase in extreme weather events • Economic concerns for agriculture dependent communities
Urban habitats and infrastructure	• Lack of clean water in urban areas. • Increase in road traffic with extreme rainfall events resulting in increase in frequency of landslides • More erosion due to spread urban growth and infrastructure development

Source: West Bengal State Action Plan for Climate Change

3.2.6 Governance

The hill region of Darjeeling comes under the administration of the Darjeeling Gorkha Hill council and the plains or Terai region, including Siliguri, comes under the Darjeeling district administration of the Government of West Bengal. These two administrative centres are responsible for all socio-economic and infrastructural facilities like health, education, roads, housing and energy as well as environmental health of the district (WBGov).

Chapter 4

This chapter is based on: Kumar, P., Geneletti, D., Nagendra, H., (under review). Spatial assessment of climate change vulnerability at city scale (Submitted to Environmental Impact Assessment Review).

4 Spatial assessment of climate change vulnerability at local level: an overview of an Indian city, Bangalore

4.1 Introduction

Climate change is anticipated to be a significant factor that will effect physical and social changes in urban areas in the future (Field et al., 2014; IPCC, 2007; Rannow et al., 2010; Stern, 2006b). Climate change causes stress to cities by increasing the frequency of heat waves, affecting the health of the population and disrupting water conditions by drought or flooding. Most nations and urban regions of the world are already facing adverse impacts of climate change, which are expected to worsen in the coming decade (Parry, 2007c). Urgent action needs to be taken on climate change through various adaptation responses along with mitigation strategies in our policy making process at all levels of spatial scale (Field et al., 2014). This is especially true at local levels, because such initiatives and policy implementations demand a bottom-up approach for design and implementation. However, in order to develop appropriate response actions to adapt to undesirable impacts of climate change, policy makers should understand the significance of the climate change issue, and be able to utilize information on the drivers of climate change and patterns of vulnerability at local spatial scales (Kumar and Geneletti, 2015).

Unfortunately, the information required to develop response actions to climate change impacts at local spatial scale are hard to find, especially in developing nations where vulnerability is high, and there is a critical need for informed action (Field, 2012; Rosenzweig et al., 2011). Most accessible information is available at higher spatial scales including the global, national and regional level. It is difficult to downscale existing datasets to provide reliable climate risk information required for city development strategies (Biesbroek et al., 2009).

Mainstream vulnerability assessment is an important component of the policy making process, aiming to inform action responses that can reduce the associated impacts of climate change (Füssel and Klein, 2006; McCarthy, 2001). The concept of vulnerability has been debated, discussed and used in many fields such as social sciences, disaster management and ecology over the past three decades (Füssel and Klein, 2006). Its variation in use across different disciplines generates problems for its definition, description, operationalization and consistent use across locations (Hinkel, 2011; Preston et al., 2009). Although there are many vulnerability assessment measures of climate change, in practice, these either target long-term mitigation strategies (EEA, 2008; Preston et al., 2011), assess vulnerable sectors or locations for the impel design of adaptation measures (Lung et al., 2013). In addition, a majority of them are developed at coarser spatial scales (Field et al., 2014; Rannow et al., 2010).

Vulnerability assessment frameworks and methods defined at coarser spatial scale are difficult to implement at local levels (Holsten and Kropp, 2012; Kumar et al., 2013; Rannow et al., 2010). This is evident by the fact that the few comprehensive vulnerability assessment studies at regional spatial scale are very general, demonstrating the difficulty in translating output and knowledge into policies given that they do not define the degree and magnitude of the results. One of the fundamental challenges in formulating vulnerability assessment frameworks at local levels is that there is no standardization of methods (Preston et al., 2011). A review of the presently available assessment methods demonstrates a lack of clarity and consistency in the selection of indicators, aggregation of different indicators, and comparison across indicators (Eriksen and Kelly, 2007; Rannow et al., 2010). It has become a practical challenge to apply and replicate available vulnerability assessment methods at local spatial scales (Hinkel, 2011; Hofmann et al., 2011; Preston et al., 2011).

According to Preston, et al.(2011) to operationalise vulnerability assessment, it is important to understand the spatial context of the assessment. Internationally, emphasis is being placed on the need for detailed studies of climate change vulnerability, resilience of space, mitigation and adaptation measures at the local scale, at specific locations (Baumert et al., 2005; Hunt and Watkiss, 2007; Metz and Davidson, 2007; Rosenzweig et al., 2011). The majority of studies at the local scale highlight issues of climate change impacts on developed nations, especially on coastal regions where impacts due to sea level rise and natural disasters are more apparent (Castán Broto and Bulkeley, 2013; Hunt and Watkiss, 2011). However there is a strong need to study climate change issue of cities in non-coastal regions as well, especially from developing nation, where variance and magnitude of climate change issues is extreme and understudied (Hanson et al., 2011; Rosenzweig et al., 2011). Also, urban systems need to be better conceptualized as a coupled socio-economic and ecological unit (Daron et al., 2014; Engle, 2011; Forman, 2014). Socio-economic aspects of the city include the urban fabric, wealth, and demography, institutional and physical components. The ecological aspects include the environment, ecosystems and natural resources. Each aspect of the urban system has its characteristics that generate sensitive and carrying capacity through interactions with other components (Plummer, 2010; Walker et al., 2006). This is particularly important for cities in semi-arid locations, where water stresses due to climate change are becoming increasingly apparent, constituting “wicked” problems for climate change adaptation (Churchman, 1967; Toman, 2014).

This study presents a methodological framework to assess vulnerability patterns to climate change at local level. The framework will help to assess vulnerability patterns, and generate maps of spatial vulnerability to aid in prioritising response actions for spatial planning policies at the city scale. The application of vulnerability assessment framework is demonstrated using as a case study an urban system in a semi-arid inland city in a developing nation: the city of Bangalore, India.

4.2 Study area

The city of Bangalore lies at $12^{0}59'$ north latitude and $77^{0}57'$ east longitudes with an area of 741 sq km and a population of 10.1 million (Figure 4-1). It is now one of the fastest growing cities in the world due to a burgeoning Information Technology hub, massive commercial industries and numerous educational institutions (Sudhira et al., 2007). Being situated central from the eastern and western coast of the south Indian peninsula, the city has a pleasant climate throughout the year (Sudhira et al., 2007). The temperatures during the summer months fall between 18^{0}C to 35^{0}C, while the winter temperature ranges from 12^{0}C to 25^{0}C. The mean annual rainfall in the city is about 830 mm with about 60 days of rainfall per year (Sudhira et al., 2007). In recent years, Bangalore urban city is facing undesirable impacts of climate change (Parikh et al., 2013; Satterthwaite, 2009). Future consequences could be observed in the economic performance, physical and social stability of the city. Bangalore has already started facing severe climate change impacts like urban heat islands, seasonal flooding and increased summer temperature (Gupta and Nair, 2011; Ramachandra and Kumar, 2010). We have chosen Bangalore city as a case study because of its climate dependency, spatial and urban developmental perspective and as a fast growing city far beyond its physical and economic limits.

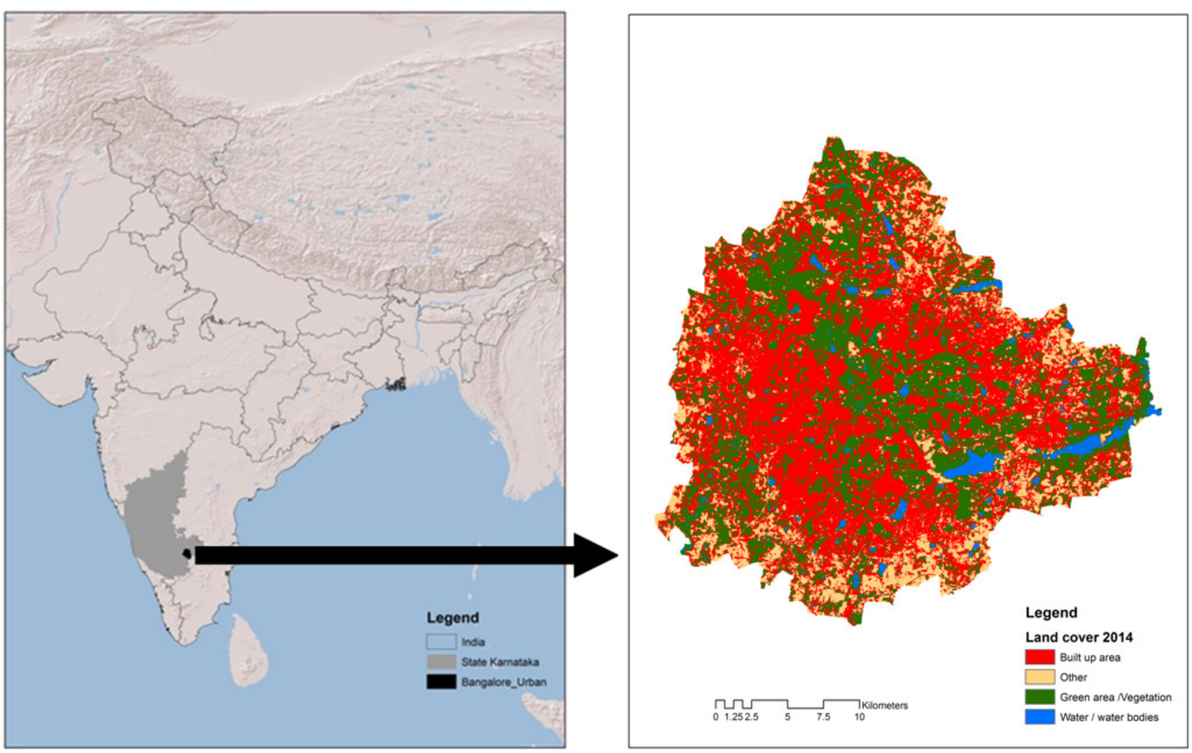

Figure 4-1: The study area Bangalore Metropolitan city, India and land cover map 2014, developed from Landsat 8 image from http://landsat.usgs.gov/ for June 2014.

4.3 Method

For this study, the formal definition of vulnerability was adopted from the work of McCarthy (2001) "the degree to which a system is susceptible to and unable to cope with, adverse effects of climate change, including climate variability and extremes". According to Füssel et al. and McCarthy (2006; 2001) vulnerability is the result of three key components: exposure, sensitivity and adaptive capacity. Vulnerability represents the current state of the system and describes the potential to experience harm from external and internal exposure due to the system's sensitivity and adaptive capacity. As per Füssel and Klein (2006), exposure describes the "magnitude to which a system is exposed to significant climatic related events" and sensitivity is the "extent to which a system is affected, either adversely or beneficially, by climate-related stimuli and the effect may be direct or indirect". Adaptive capacity is the capacity of a system to organize itself to the external and internal stresses and respond to them (Smit and Pilifosova, 2003). According to Adger et al. (2005) "adaptive capacity of any system is mostly determined by a local set of resources and conditions that limit or support the system to adapt successfully to climate changes". Interaction between exposure and sensitivity also defines the impact of climate stressors on the socio-ecological system (Holsten and Kropp, 2012). Hence, to understand the pattern of vulnerability to any system, it is a prerequisite to have comprehensive information about its key components i.e. exposures, sensitivity, and adaptive capacities: as well as impact elements, i.e. a combination of exposures and sensitivity.

4.3.1 Exposure

This study addresses exposures under the category of extreme events. Extreme events are direct physical events generated from weather and climate variables like temperature (Hübler et al., 2008), precipitation (Lung et al., 2013) and wind (Field, 2012; Vose et al., 2013).These extreme events have varied impacts at urban level depending upon the interaction with the urban system in terms of time, duration and magnitude, as well as the spatial extent and characteristics of the system. Based on past events and the nature of the current physical and environmental stress within the study area, indicators were selected for extreme event. Table 4-1 presents the indicators selected for this study to describe the exposure components.

Table 4-1: Indicators used to measure the exposure component.

Exposure	Indicators	Description	Reference
Longer and more intense hot days	1. Hot days/year (Tmax>30º C) 2. Mean temperature Increase	Changes in temperature (summer maximum and winter minimum temperatures) will result in heat and cold waves, threaten human health, lives, industries and jobs. It has also sever consequence on food security	(Hübler et al., 2008)

		like agricultural production, fresh water supplies and the health of native species and ecosystem.	
Increase in precipitation intensity and number of days of increased precipitation	1. Rain range (>830 mm/year) 2. Number of days/year with heavy rain (RR >30mm)	Changes in seasons and precipitation pattern will result in frequent events of erratic precipitation to create situations of flash floods during rainy season or drought conditions during summer season.	(Rannow et al., 2010)

4.3.2 Sensitivity

Selected sensitivity indicators were based upon the understanding of the socio-economic and ecological aspects of the urban system. Detailed study of various spatial plans, sectoral policies, primary and secondary survey of socio-ecological aspects and findings of earlier studies of the selected case study helped to identify sensitivity indicators (Ramachandra and Kumar, 2010). Sensitivity to various aspects of the urban system was analysed from the data collected from public databases like Census of India, local municipal authorities and state development department as detailed in appendix 4. Socio-ecological data from various stakeholders were also collected through field work conducted in Bangalore city during the month of February to April 2014. Selected indicators of various aspects of sensitivity components were also observed in other studies, for example, infrastructure sensitivity to climate change (Eisenack et al., 2012; Suarez et al., 2005), high density (De Sherbinin et al., 2007; Wilby, 2007), the vulnerability of slums to climate change (Banks et al., 2011; Kovats and Akhtar, 2008) , land use change (de Noblet-Ducoudré et al., 2012; Kulakowski et al., 2011; Metzger et al., 2006), the vulnerability of children and the elderly to climate extreme events (Bartlett, 2008; Han and Foltz, 2013; Huang et al., 2011; McMichael et al.) and risk to natural resources from climate change (Beniston et al., 2007; Herrera-Pantoja and Hiscock, 2008; Muller, 2007; O'Hara and Georgakakos, 2008; Sun and Chen, 2012; Wilby, 2007). The selected sensitivity indicators are presented in Table 4-2.

Table 4-2: Indicators used to measure the sensitivity component.

Broad aspects	Sensitivity	Indicators	Description	Reference
Physical and economic	Infrastructure	Area covered by road	Mobility of the people and other urban services are strongly dependent on weather conditions. Extreme climate events can have high social and economic costs.	(Szendrő et al., 2014)
	Poor living and built conditions	1. High-density area	Urban form: in particular, poorly built and managed areas: have a wide variety of implications for the	(De Sherbinin et al., 2007)

		2. Number of slums	city including increased greenhouse gas emissions, resource requirements and vulnerability to climate change impacts.	
	Future natural resources	Land use change	Land being used for the development of the new settlement, building and other public amenities that directly influence the local environment, food security and climate regulation	(Pielke et al., 2011)
Social	People at risk	Percentage of people younger than 6 years (Due to lack of data on elderly people percentage of children younger than 6 years was used as an indicator)	A combination of factor like extreme temperature, flooding are the primary stressor for children and elderly people with regard to health and development. The percentage of children and elderly population is one of the key aspects of the system's sensitive to various climate change events	(Bartlett, 2008; Han and Foltz, 2013)
	Asset sensitivity	Percentage of liveable houses	Access to safe living conditions, especially housing, is vital to build the resilience of people.	(De Sherbinin et al., 2007)
Environmental	Basic natural resources	Increased fluctuation of groundwater levels	Changes in seasonal precipitation and its magnitude can cause fluctuations of groundwater levels. This process could increase or decrease the ground water level and create situations like drought or flooding.	(Rannow et al., 2010)
	Ecosystem and biodiversity	Loss of lakes and wetland area	Changes in climate variable like temperature and precipitation has multiple impacts on biodiversity or local ecosystem like change in habitat conditions, loss of ecosystem services and biodiversity patterns.	(Mundoli et al., 2014)

4.3.3 Impact

Interactions between exposure and sensitivity components within a spatial context determine the potential impacts of climate change (Holsten et al., 2011; Parry, 2007a; Rannow et al., 2010). Thus, impacts focus on the effect of extreme events of climate change on the urban system without considering its coping capacity. For this study, Impacts were determined by aggregating final output values of exposure components and each aspect of sensitivity. After calculating the individual impacts of physical and economic, social and environmental factors, the overall impact on the urban system due to all these aspects was determined by giving weight to each impact and aggregating.

Table 4-3: Indicators used to measure the adaptive capacity component.

Aspects	**Adaptive capacity**	**Indicators**	**Description**	**Reference**
Socio-economic	Micro-finance	Percentage of household having banking facilities	Better economic state and accessibility to financial services to t people, are necessary to build adaptive capacity. A large proportion of people do not have access to proper banking services that cause economic deprivation.	(Lung et al., 2013)
	Social structural context	• Percentage of households having housing ownership • Percentage of households having all kind asset ownership	Ownership of physical assets is vital for building the resilience of people. Accumulation and allocation of assets is related to their livelihood strategy and provides financial returns to asset portfolios, as well as coping capacity to various shocks.	(De Sherbinin et al., 2007; Dodman and Satterthwaite, 2008)
	Livelihoods and awareness	Percentage of people who are literate	Education is a crucial aspect for climate change awareness as well as for means of livelihoods. Education helps to promote and facilitate the development and implementation of various response actions to climate change.	(Holsten and Kropp, 2012)
Provision of basic facilities	Basic amenities	• Percentage of households having drinking water connection • Percentage of households having waste water drainage connection • Percentage of households connected to efficient cooking fuel	Local governments play a key role by ensuring equal distribution of local resources, facilities and opportunities to people. Lack of basic amities can lead to an area being vulnerable to climate change impacts and may later impose additional costs on deprived people.	(Banks et al., 2011; De Sherbinin et al., 2007)
	Public	Percentage of areas	Inaccessibility to public infrastructure	(Szendrő et al.,

	infrastructure	having road access	can lead to stranded people during extreme events as well as hampering the capacity to provide distress relief	2014)
Ecological	Green infrastructure	• Green space/ per person • Percentage of area under lakes	Urban green spaces and restored water bodies have been shown to provide a number of environmental and social benefits like local climate stabilization, energy use. it is particularly important for eco-system based adaptation response to climate change like urban heat island effects, increase carbon storage, water and purification. Social benefits include mental and physical health and food products like fish from lakes.	(Mundoli et al., 2014; Vailshery et al., 2013)

4.3.4 Adaptive capacity

Adaptive capacity is a reflection of the strength of the socio-ecological system. The measure of how an urban system has implemented adaptation measures in the past and how socio-economic and ecological aspects have been prepared to various exposures in the current and the future scenarios is the adaptive capacity (Adger et al., 2005a). Based on the literature review and availability of the data, three aspects of the urban system were chosen for measuring the adaptive capacity for this study as shown in Table 4-3. With the help of socio-economic aspect of adaptive capacity we try to understand the socio-economic condition of the people in the urban system like housing ownership and assets (Berman et al., 2012; Dodman and Satterthwaite, 2008; Sen, 1983), banking and loan facilities (Holsten and Kropp, 2012; Lung et al., 2013), education level (Engle and Lemos, 2010; Field, 2012) etc. The provision of basic facilities is related to the accessibility of people to essential services provided by the local governmental institution like access to potable drinking water (Eakin et al., 2010; Pahl-Wostl, 2007), houses connected to waste water drainage (Ashley et al., 2007; Dodman and Satterthwaite, 2008; Eakin et al., 2010), access to road and energy (Dodman and Satterthwaite, 2008) etc. In addition to above, accessibility of people and local communities to the healthy and clean environmental is also essential. This is because green spaces and water bodies in an urban areas provides local microclimate mitigation for example through the shade provided by tree or gardens (Breuste et al., 2013; Vailshery et al., 2013), reduce overall energy consumption by reducing the temperature (Jim and Chen, 2008; Kabisch and Haase, 2014), and reduce noise and increase carbon storage etc. (Strohbach and Haase, 2012).Water bodies in cities maintain underground water table, provide water, food and recreational space to the people as well as home to some of the endangered biodiversity hotspots (Mundoli et al., 2014). The building of a comprehensive adaptive capacity for any system depends upon the spatial extent of the local system and coping strategies of the local government.

4.3.5 Assessing potential vulnerability pattern

Potential vulnerability pattern was analysed spatially and results were compared at the city and ward (administrative sub-unit within the city) level. Vulnerability components and indicators were combined by means of Spatial Multi-Criteria Evaluation (SMCE) method (Geneletti, 2010; Uribe et al., 2014). The theoretical background for the multi-criteria evaluation was adapted from Frigerio & van Westen (2010)'s conceptual framework of risk, hazard and vulnerability. The first step of the SMCE method was to define the problem in the form of a 'criteria tree' consisting of all spatial and non-spatial indicators identified as components of the vulnerability assessment framework. Once the criteria tree was prepared, standardisation of each indicator was carried out based on the critical range (see Supplementary Material, SM). Standardisation converts original values of the indicator into a 0 to 1 scale to compare and aggregate the results of all the indicators. After standardisation, weighting of components and indicator under each component was carried out. The weighting and standardisation process was based on field work experience, knowledge gained from primary survey, stakeholder interviews and results from earlier studies. At each level of the hierarchy, there is an option for weighting the indicator and components based on its contribution, performance to the overall goal and critical breakpoint within the system when it changes its structure from stable to unstable based on literature (Greene et al., 2011; Malczewski, 1999, 2006) as shown in Figure 4-2. The final results are presented in the form of maps that depict the spatial pattern of vulnerability to climate change.

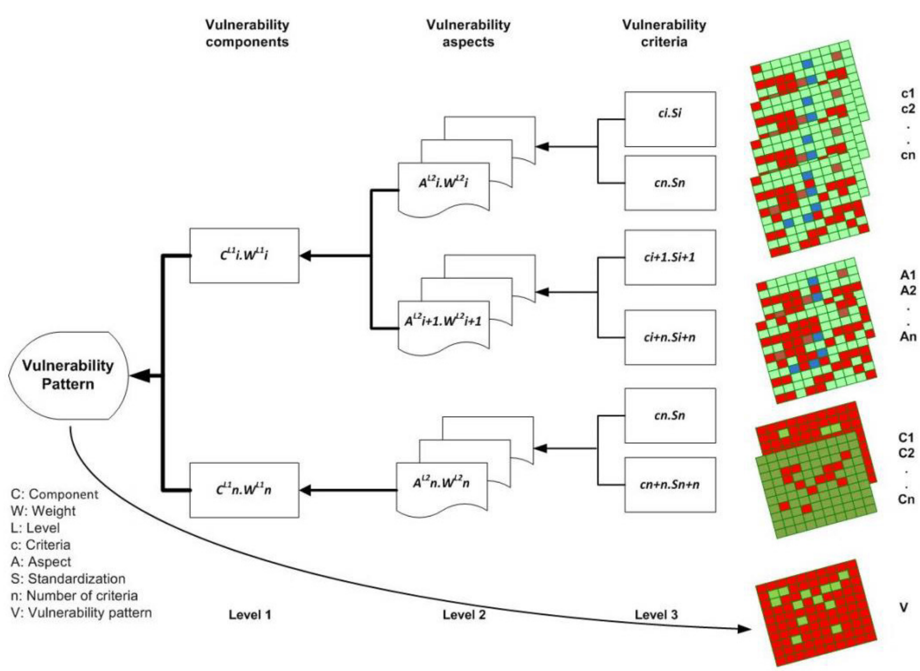

Figure 4-2: Schematic overview of spatial multi-criteria evaluation (SMCE) for climate change vulnerability assessment

4.3.6 Cluster analysis

This study uses cluster analysis as one of the tools to understand the vulnerability profile of the Bangalore city. Cluster analysis categorizes the data into groups or clusters that share similar characteristics. The objective of this step was to explore the clustering/scattering pattern of the overall vulnerability at the component level, providing a detailed profile of the most vulnerable hotspots in the study area. Clustering analysis is a standard approach used in a vast array of environmental studies (Holsten et al., 2011; Janssen et al., 2012; Kok et al., 2010). The vulnerability profiles were categorised into three classes namely, very high, high and medium based on a scale of 0 to 1. The range of 0.5 to 0.6 was considered medium, 0.6 to 0.7 was considered as high vulnerability and above 0.7 was considered as very high vulnerability.

In addition to this, the Fraiman measure was applied at three levels, namely at the component, aspect and indicator levels of the vulnerability assessment. The Fraiman measure represents the importance of a variable in the resulting output and is defined as 'smaller the Fraiman measure of a variable, larger the influence of that variable on the resulting output'(Kok et al., 2010).

4.4 Results

4.4.1 Exposure

The majority of the area of Bangalore city was found under high exposure from different climate stimuli. About 38% of the total area was seen to be facing severe exposure. The spatial distribution of the exposures showed stronger effects in the north and north-eastern region and some wards in the southern region of Bangalore city as shown in Figure 4-3. Increased number of days with intense rain (RR > 30mm) and hot day (Temp>30^{o}C) were the key indicators that influence the exposure component. Even after conducting sensitivity analysis by changing the weights of different indicators, the same areas were seen to facing severe impacts from climate stimuli. The entire eastern to the southern region of the city was seen to be facing increased number of hot days (Temp>30^{o}C) compared to the other part of the city. However, it was also observed that there is an increase in mean temperature in all the wards ranging from 0.37 ^{o}C to 0.48 ^{o}C for the past ten years. Trends in mean temperature for the last decade showed that there is a persistent increase in temperature for most regions in Bangalore city with the northern and eastern regions showing higher ranges. Some of the reasons for this change are extensive land use change and urban development. In the case of precipitation, majority of area in the city was seen to be facing increased number of days of high-intensity rain (>30mm) that makes Bangalore city vulnerable to extreme events like flooding in low-lying areas like the periphery area of western and eastern regions. While, variation in annual average rainfall was extensive in the northern regions of the city, facing an increase in above average rainfall, a few wards in the eastern and southern regions showed decrease in annual average rainfall. However, there is a possibility that in the future the eastern regions could face drier conditions and drought periods during the summer months of the year because of increasing difference in pre-monsoon and after monsoon rainfall and stressed condition of ground water level. High degree of land use change due to urbanisation, hazardous growth of urban fringes, poor living conditions and lack of basic facilities make the city more vulnerable to climate stimuli.

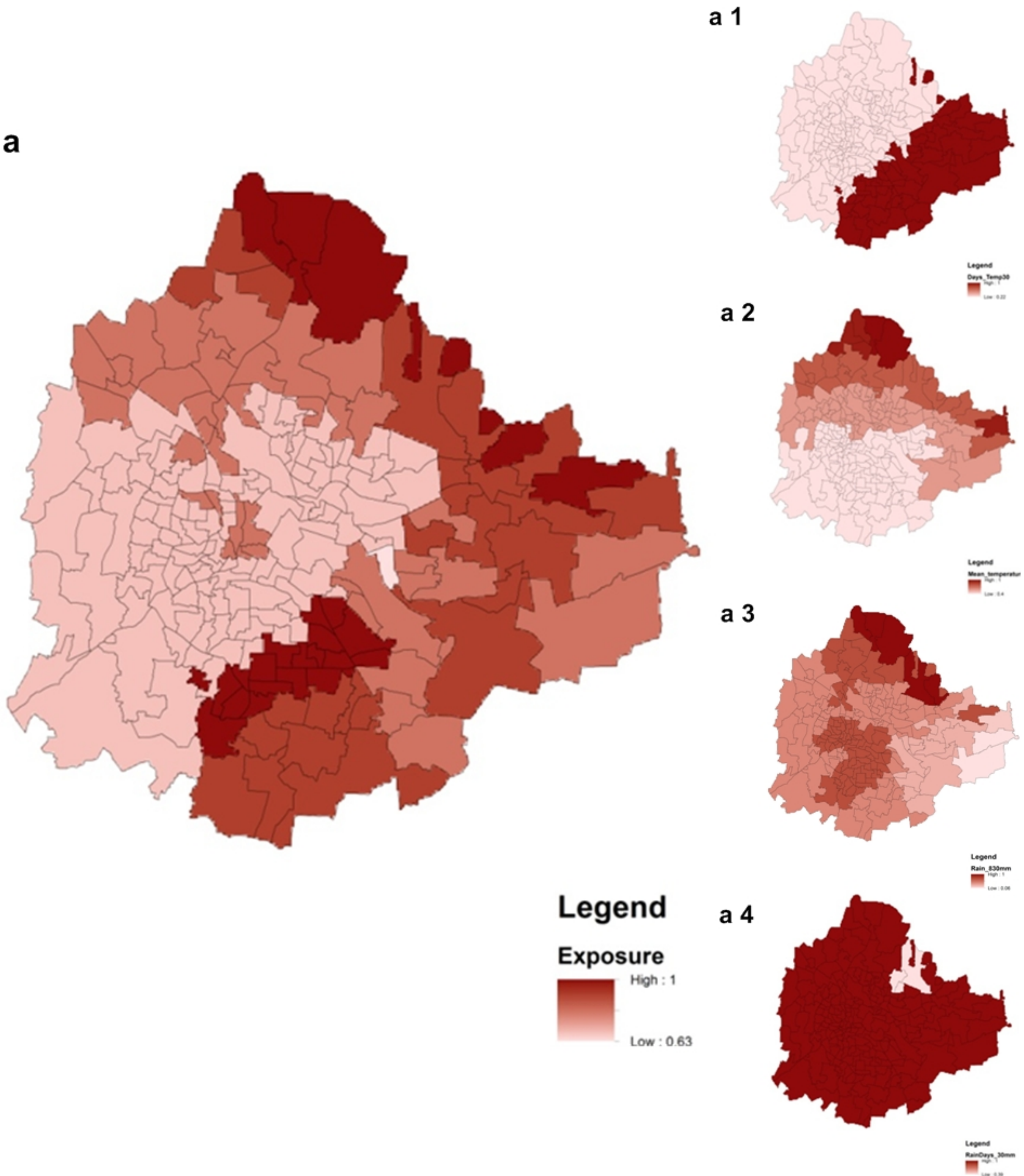

Figure 4-3: Spatial distribution of the exposure components of climate change vulnerability and aspects of exposure component a)Exposure, a1) Number of days of temperature above 30oC, a2) Mean temperature, a3) Rainfall greater than 830 mm and a4) Number of days above 30 mm rain.

4.4.2 Sensitivity

The magnitude of the sensitivity component of Bangalore city was found to have an average range as shown in Figure 4-4. Spatial distribution of sensitivity component showed that the central region and the periphery of the western to the southern region of the city were more sensitive to different climate stimuli than other regions. Most regions of Bangalore city was seen to be sensitive to changes in social and environmental aspects and least to physical and economic aspects. Social and environmental aspects of sensitivity component contributed to a high degree in the overall sensitivity of Bangalore city. According to physical and economic aspects of sensitivity component, central region of Bangalore city is sensitive to climate events. Spatial distribution of social aspect of sensitivity showed that approximately 5% of the total area, mainly in the central region, was highly sensitive and about 55% of total area of Bangalore city in the southern, northern to western and eastern region of Bangalore city were at high level of risk to climate change impacts. Lastly, the environmental aspect of sensitivity was seen to be highly sensitive and contributed the most to the overall sensitivity of Bangalore city. About 32% of total areas of Bangalore city were seen to be sensitive to climate stimuli and human intervention. The overall sensitivity analysis showed that the periphery of the western to southern, eastern regions of Bangalore city and a few pockets in the central region were observed to be vulnerable. Mainly because these regions are either socially vulnerable in term of people lacking in awareness, basic facilities, accessibility and multiple deprivation and at the same time these are also region that are undergoing rapid urbanisation that has lead to unplanned periphery areas and deteriorated natural environment etc.

4.4.3 Impact

The high impact areas of climate change are predominantly distributed towards the periphery of the north, east and southern region of the city as shown in Figure 4-5. The percentage of area facing the magnitude of impact above 0.5 was found to be 90.1% of the total area of the city. About 12.5% of the total area is facing severe impact of climate change (above magnitude 0.7). It was found that Bangalore city has limited physical impacts from climate events. About 1% of the total area showed high sensitivity to various climate phenomena. Some of these areas were poorly built with slums pockets and low-lying area and faced severe impact from rain in the form of flash flooding every year. The climate impact on social structure of Bangalore city showed that about 35% of the total area was facing impacts of climate change in the magnitude of above 0.5. In addition, 6% of the total area was seen to be suffering severe impact of climate change at a social level (above 0.7). These severely at-risk social areas were dominant in the eastern, northern and a few pockets in the central regions of the city. The impacts of extreme climate events and changes in climate variables have affected the environment the most with most of the natural areas in the city being highly sensitive. Environmental and social aspects of sensitivity were among the primary predictor for the overall impacts of different climate stimuli.

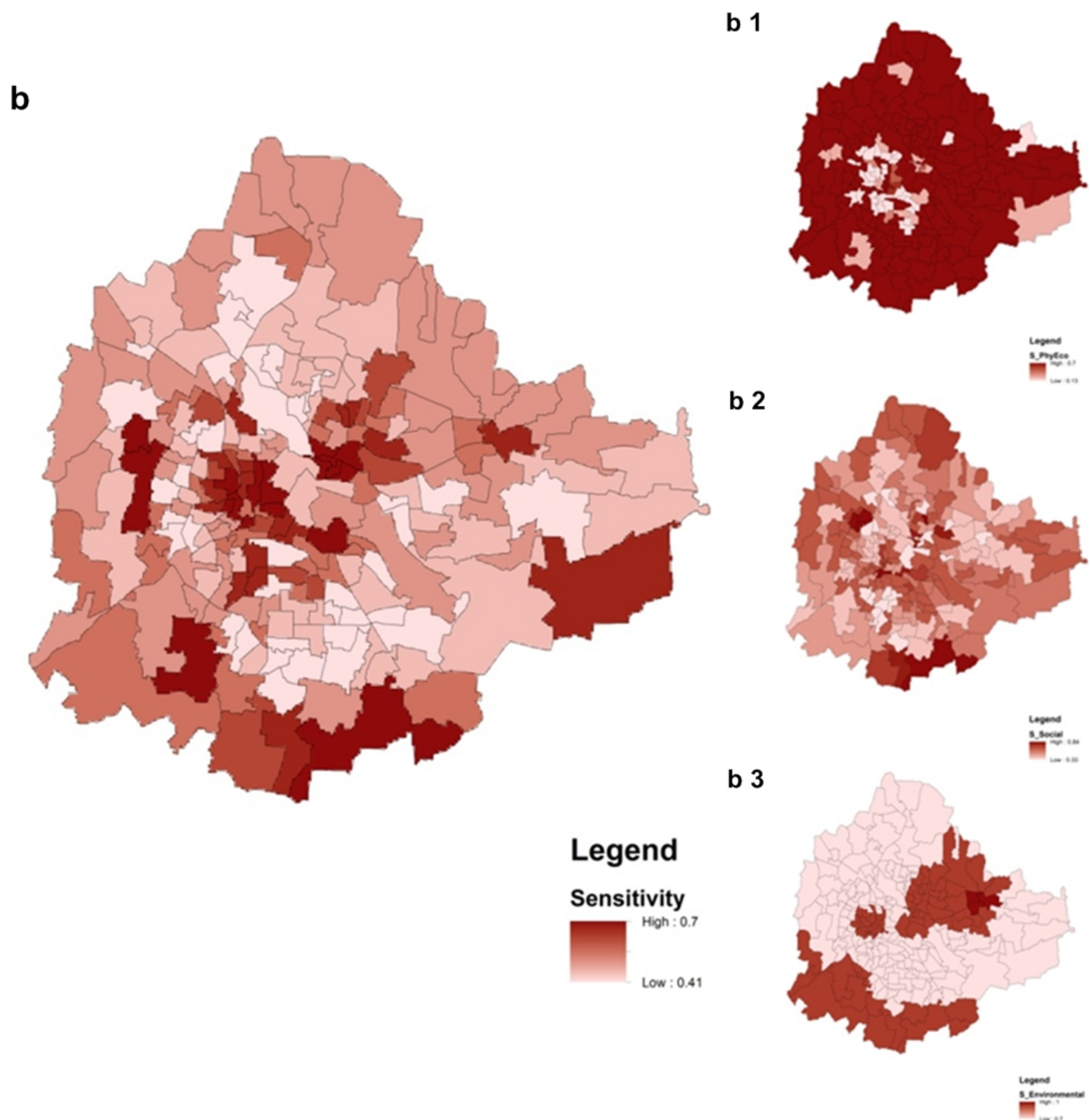

Figure 4-4: Spatial distribution of sensitivity component of climate change vulnerability and aspects of sensitivity component b) sensitivity, b1) Physical and economic aspect, b2) Social aspect and b3) Environmental aspects.

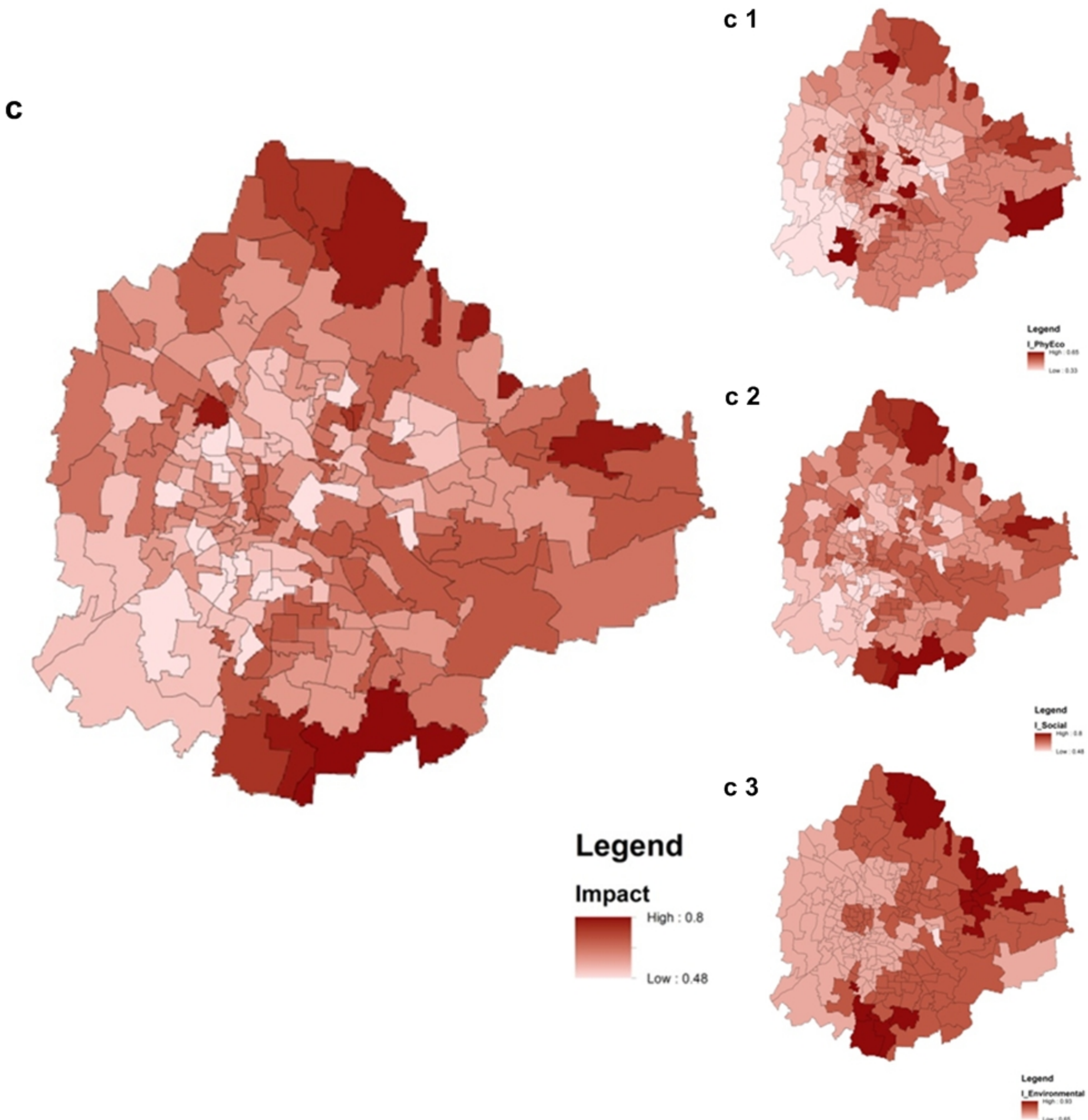

Figure 4-5: Spatial distribution of climate change impacts and aspects of impact c) sensitivity, c1) Physical and economic aspect, c2) Social aspect and c3) Environmental aspect.

4.4.4 Adaptive capacity

Figure 4-6 shows the spatial distribution of adaptive capacity. The overall adaptive capacity of Bangalore city was of a medium magnitude ranging from 0.4 to .6. It was found that the central region of Bangalore city had higher adaptive capacity than other parts of the city. Adaptive capacity was also found to be higher in those regions that had active economic activities, high density of institutional areas and well-developed basic infrastructures. However, most of the periphery areas with small villages and new developmental areas had low adaptive capacity. The reason for this is likely to be poor condition in term of basic infrastructural services, little economic activity and low awareness. About 20% of the total area of the Bangalore city had a high adaptive capacity with magnitudes above 0.6. Considering the socio-economic aspect of adaptive capacity, it was observed that the social adaptive capacity was high in the central region of the city and low at the periphery of the western, southern and some pocket in the central region of the city. Adaptive capacity measured in terms of provision of basic facilities was moderate, with only 7% of the total area with high accessibility to basic facilities, 50% with moderate level and approximately 40% with low-level accessibility to necessary services. As for the environmental aspect of adaptive capacity, about 35% of total Bangalore city had sufficient access to green infrastructure like green open spaces, gardens, lakes and wetland areas. About 60 % of the total area of Bangalore showed below minimum access to green infrastructure.

4.4.5 Overall vulnerability

The overall vulnerability pattern of Bangalore city to climate change is presented in Figure 4-7. The distribution closely resembles the results of the impacts of climate change in Bangalore city. Northern, eastern and southern region of Bangalore city, seen to be high-impact regions in Figure 4-7, were even more predominant in the overall vulnerability assessment results. These results are because of the high influence of the sensitivity and exposure components in these areas. However, it is also observed that the regions having high overall vulnerability to climate change also seem to have low adaptive capacity (comparing with Figure 4-6). Ward-wise result of vulnerability assessment is also presented in the appendix 5.

4.4.6 Potential vulnerability profiling

Cluster analysis helped to profile the potential vulnerability to climate change as per the severity into medium, high and very high vulnerability. These overall vulnerability profiles are presented in Figure 4-8. The vulnerability profile shows the severity of vulnerability and areas that need urgent response action across Bangalore city. Areas of high vulnerability profile were seen to be sensitive to most climate stimuli and at the same time showed frequent occurrence of severe climate events. A comparative study of the vulnerability assessment maps revealed that these regions showed low levels of sensitivity, medium level adaptive capacity and high level of influence from various exposures. The spatial distribution of the very high vulnerability profile could be observed on the periphery of the northern, eastern and southern regions of Bangalore city with a spatial coverage of about 4% of the total area. Approximately 91% of the total area was calculated as having high degree of vulnerability. These regions had medium adaptive capacity and low sensitivity to various climate exposures. However, it is likely that in the future these regions will shift to the high vulnerability profile because of the increase in extreme weather events, decrease in sensitivity and decrease in adaptive capacity. 5 % of the total area of Bangalore city falls under medium magnitude of vulnerability. These regions are located in a few pockets in the central area and western region of Bangalore city. These regions have a high level of adaptive capacity and low level of sensitivity and exposure.

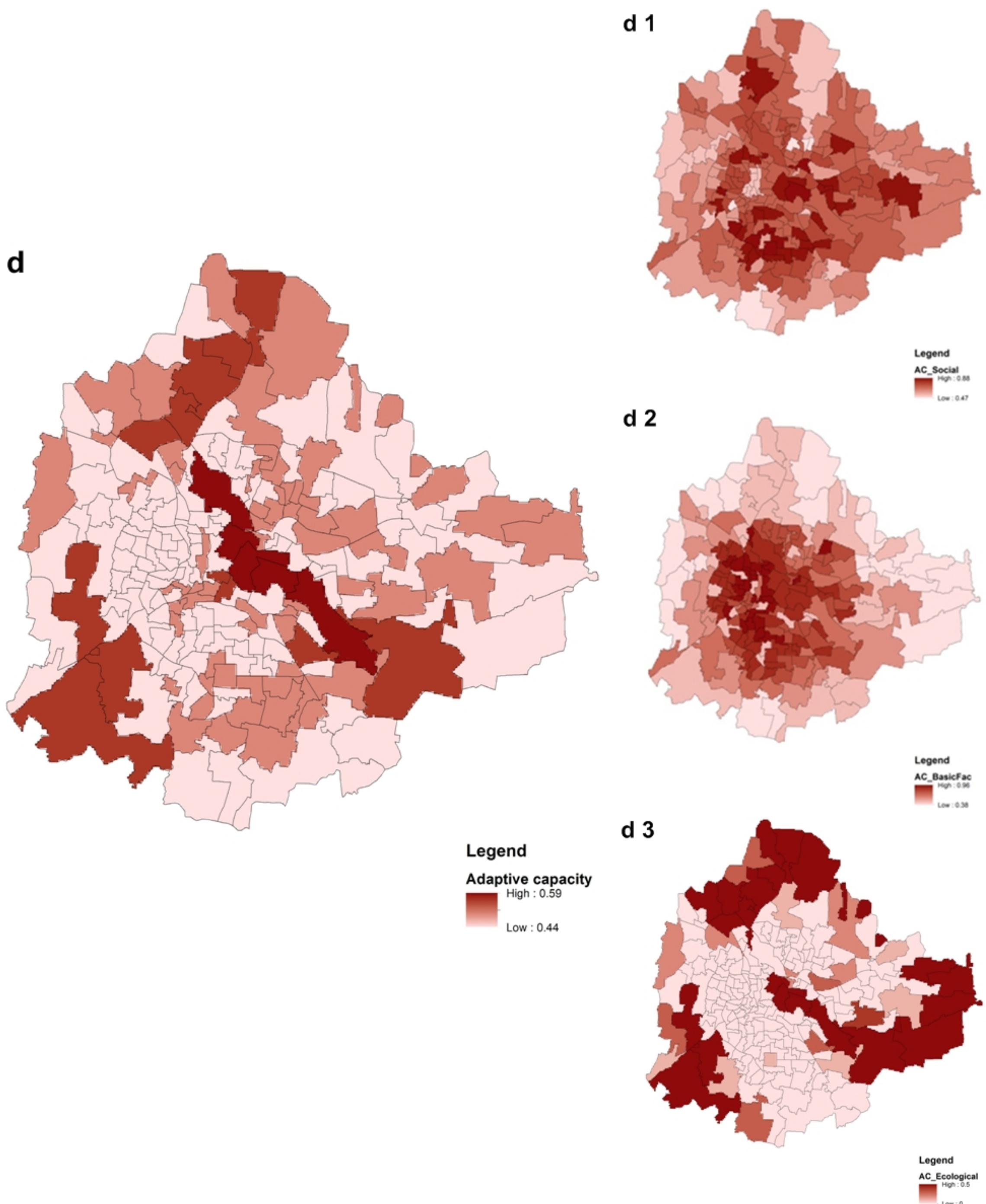

Figure 4-6: Spatial distribution of adaptive capacity component climate change vulnerability and aspects of Adaptive capacity component d) Adaptive capacity, d1) Social aspect, d2) Basic facilities aspect and d3) Ecological aspect.

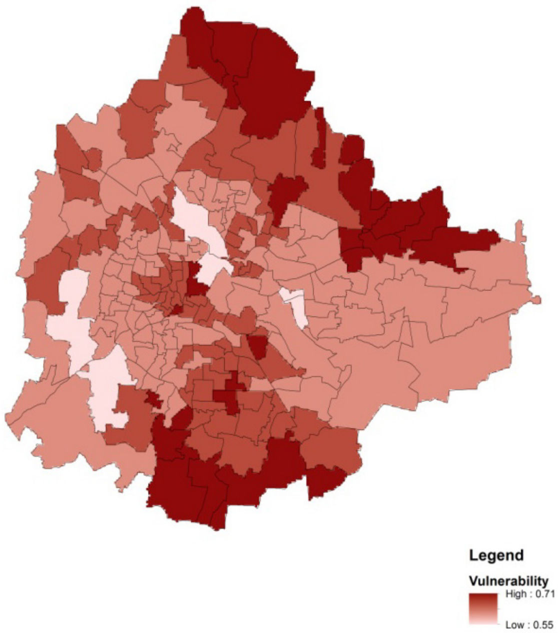

Figure 4-7: Spatial distribution of overall vulnerability

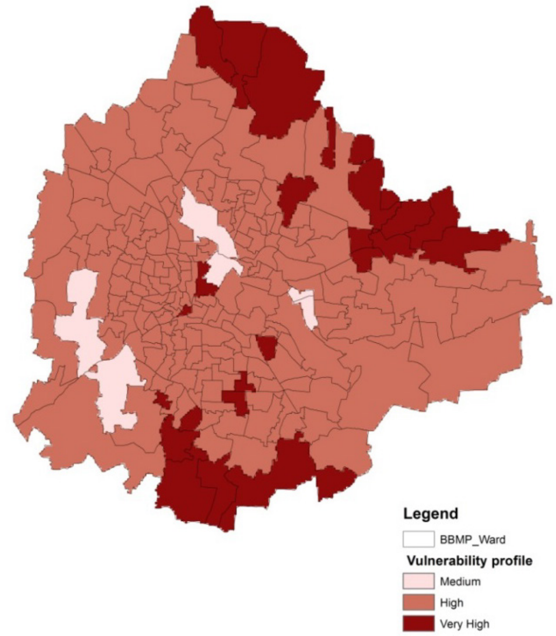

Figure 4-8: Potential vulnerability profiles. to climate change.

The Fraiman measure indicates that the sensitivity is the most critical component to the overall vulnerability assessment (Figure 4-9). While Fraiman measure of all the aspects shows that the social and environmental aspect of sensitivity and ecological aspect of adaptive capacity components were the primary factors influencing vulnerability assessment (Figure 4-10). At the indicator level, the Fraiman measure gives a variety of indicators from all the components that were relevant to overall vulnerability like loss of lakes and wetland area, per capita green space, land use change, increase in days per year with heavy rainfall and increase in hot days per year were some of the driving indicators for vulnerability (Figure 4-11).

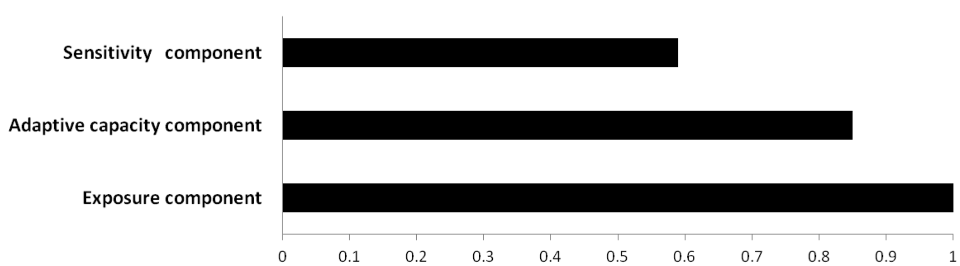

Figure 4-9: Fraiman measure for components of vulnerability assessment (Remark: the smaller the value, the larger the influence of a particular component in the resulting output)

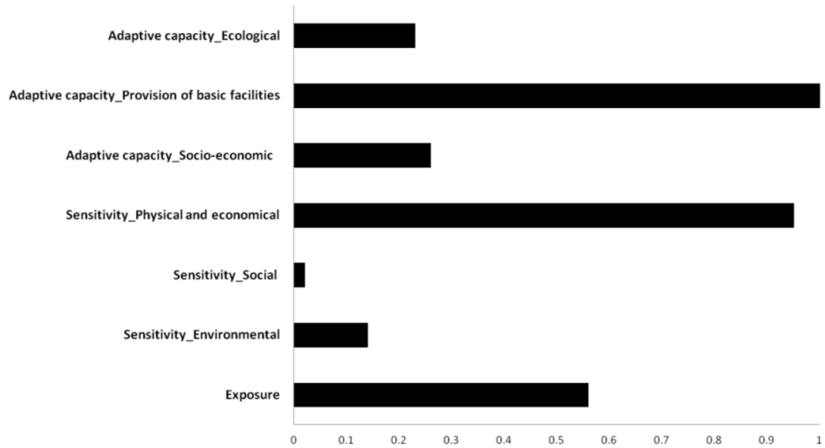

Figure 4-10: Fraiman measure of all the aspects of vulnerability assessment

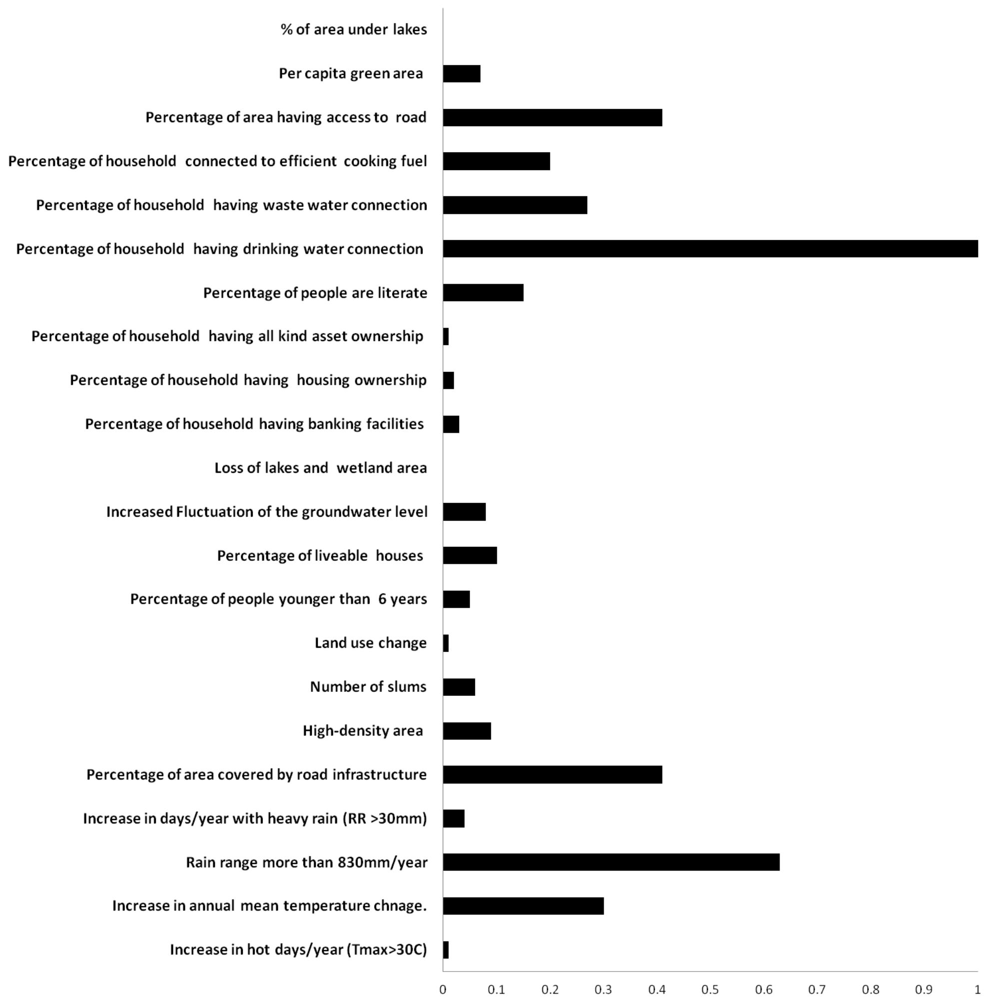

Figure 4-11: Fraiman measure of all the indicators of vulnerability assessment

4.5 Discussion

This study presents a vulnerability assessment framework to climate change that allows the evaluation of vulnerability patterns of the urban system to different climate change issues and also provides a spatial profile of these vulnerabilities.

Despite the mutual agreement concerning the concept of climate change vulnerability and its key components within the scientific and policy-making communities, there is still a severe lack of standardized vulnerability assessment methods procedures for application at the local scale (Costa and Kropp, 2013; Füssel, 2007; Holsten and Kropp, 2012; Preston et al., 2011). This lack of standardisation has led to the flourishing of subjective assessment methods that may not be sufficient for developing action responses at the local scale (Preston et al., 2011; Rannow et al., 2010). Outputs and knowledge derived from such methods are very general and difficult to translating for the development of the response action to climate change.

Currently, majority of cities in developing countries lack the necessary information on climate change impacts to produce response actions in different sectors (Measham et al., 2011; Tribbia and Moser, 2008). Most cities in developing countries, especially in India are still evolving and struggling to deal with fundamental issues like provision of necessary facilities, basic infrastructure, poverty alleviation, population growth and social disparities. Additionally climate change impacts prove to be a heavy exertion on institutional and financial capabilities.

In this study, we try to adapt the local issues and concern related to climate change within the spatial planning practices that can potentially help in developing action responses for different sectors. For example, the analysis of the exposure component represents the effects of extreme weather conditions and probability of drought or flood conditions in different regions. This information can be used to implement action responses to deal with water and wastewater related issues such as modifying ground and surface water sources to address supply vulnerabilities during flood and drought conditions, encouraging innovation local supply techniques such as rainwater harvesting and water reuse, exercise demand management of water through pricing policies, leak detection ad unauthorized use and better toilet and shower codes.

In addition, an important feature of this study is that we have tried to assess all possible components, aspects and indicators at same spatial scale. Therefore, it is also significant that all the results presented at same scale and is consistent with the scale at which spatial planning and sectoral policies are developed at a local level.

To target mitigation and adaptation action response at local level comprehensive information at the same scale were derived from the application of vulnerability assessment framework. The framework presented provides inclusive information at ward level and helps to prioritising action response to climate change through policy interventions within the spatial planning process. For example, vulnerability profiling of the urban area contributes to identifying the area that needs urgent attention in the form of adaptation response. Based upon the magnitude of the impacts collective or individuation response action could be developed. Results of vulnerability assessment showed that the periphery of the northern, eastern and southern regions of Bangalore city showed high vulnerability to the climate change impacts. The analysis also showed that these are also the same regions that are facing higher magnitude of exposures ranging from 0.9 to 1 in the form of increased number of hot days/year, increase in annual mean temperature and increased number of days/year with heavy rain (RR > 30mm). These regions also seem to have show high sensitivity to physical, social and environmental aspects with values ranging from 0.5 to .7. With such high exposure and sensitivity to climate change issues, these regions require a higher adaptive capacity.

For example, the results of the adaptive capacity showed that most wards that are highly vulnerable have low levels of adaptive capacity. It was observed that two key aspects of adaptive capacity, namely, ecological and basic services, were extremely poor in these wards while social integration aspects was seen to be relatively better. In this situation the local government, with the help of the local community can developing short term solutions like planning trees, green roofing, restoration of lakes from encroachment and awareness and controlled land use change that can contribute to reduce physical impacts of climate change. Over the long term, policymakers can focus on reducing the structural processes of inequalities in distribution and providing access to basic infrastructures, health services, improved living environment, in addition to addressing the economic and social marginalization of individual wards and regions that limit opportunities to enhance well-being and enable adaptation to various impacts of climate change (Romero Lankao and Qin, 2011)

Outputs of vulnerability assessment framework have also identified different sectors for example loss of lakes and wetland area, per capita green space, land use change, accessibility of necessary infrastructure to people and location of highly vulnerable social groups such as children and slum residents that required urgent attention and integration within local level policies in Bangalore city. This could occur through spatial planning policies.

The framework presented in this study provides comprehensive information at ward level and will be useful in prioritising action response to climate change through policy interventions within the spatial planning or general policy processes. Presently spatial planning practice, or even general policies in different cities in India are based upon biased and unjustified conclusions, very basic quantitative analyses makes public decisions difficult and does not allow for fair trade-offs between priority and non-priority issues (Reckien, 2014; Roy, 2009; Wilson and Piper, 2010). This study tries to resolve these issues by identifying the contribution of each indicator to a comprehensive assessment. Furthermore, ranking of the priorities spatially and at sector level allows a comparative analysis to apply various small interventions rather than a single dominant intervention.

This study presents a rational and simple vulnerability assessment framework to be operational at any local level that can help to prioritize response action either independently or in the spatial planning process. However, selection of indicators under each vulnerability component should be adapted with relevance to a specific region. This step is crucial as it has a larger influence on the overall outcome of the assessment. For the application of the framework in the selected case study, one of the key issues was the availability of critical data and detailed information required by the vulnerability assessment framework. A large number of urban regions in developing countries do not maintain historical records on a different aspect of the urban system and climate variables (Laukkonen et al., 2009). Available databases are unstructured and sometimes irrelevant. It is also difficult to assess the quality and source of databases because of the presence of multiple organizations within in a region. In India, for example sometimes government institutions are not aware of data availability within and other government or private organizations. These issues can lead to biases and uncertainties in the assessment method. Also, lack of coordination and partnership among various groups and stakeholder during the planning process and decision making at local level create problems in implementation of actual response actions to climate change issues. For example, in the case of Bangalore allowing private developer to build commercial and residential building on green space and seasonal dried lakes of city not only create environmental issues but also affects the social fabric of city without considering the consensus of local people.

The study also provides information on potential difficulties and gaps to conduct climate change vulnerability assessment at a local level. A few limitations of the assessment framework lie in the subjectivity linked to the selection of indicators, standardization and giving weights. That can be easily solved if all the major stakeholders involved in the conceptualization and problem development stage of the climate change vulnerability assessment.

Chapter 5

This chapter is based on: Kumar, P., Geneletti, Bawa, K. (in preparation) Spatial assessment and perception of people to climate change in Darjeeling Himalaya.

5 Spatial vulnerability assessment and perception of people to climate change in Darjeeling Himalaya

5.1 Introduction

Mountains account for about 24% of the total terrestrial area of the world with 26% of total world population living in or on the foothills of mountains. Approximately 40% of the total world population directly or indirectly are dependent on its ecosystem services (Beniston, 2003; Meybeck et al., 2001). It is therefore ominous that mountains are one of the most fragile socio-ecological systems of the world being extremely sensitive to the effects of climate change (Schild, 2008). However, mountains also have distinct characteristics that make detection and assessment of climate related issues easier making them interesting subjects and live laboratory for many research organisations for studying climate change impacts (Beniston, 2003; Kullman, 2004; Salick et al., 2009).

Significant events of climate change across mountain regions of the world are visible through glacial recession, warming of mountain, extreme precipitation events, natural hazards, loss of human life and extinction of biodiversity (Du et al., 2004; Jianchu et al., 2009; Maraseni, 2012). As mountains are rich in biodiversity which show sharp transition zones (ecotones), immediate and first impacts of climate change are more evident in the form of early plant blooming, extinction and shifting of plant species and migration of animals from low to higher altitudes (Byg and Salick, 2009; Myers et al., 2000). The reason for these conspicuous effects of climate change in mountain regions is that as temperature changes rapidly with height in these regions, it affects the biodiversity and hydrology in its wake (Beniston, 2003; Whiteman, 2000). Changes such as these consequently effects the diverse ecosystem services that mountains provide for the populations living in these regions and the adjacent lowlands causing distress to the social, economic and political fabric (Macchi et al., 2011). Sharp differences in terrain and complex socio-ecological system makes climate studies demanding in these regions and raise significant concerns to adaptation, especially in developing nations in south East Asia and Africa (Beniston, 2003; Velma I. Grover et al., 2014).

During the United Nations Conference on Environment and Development (UNCED) in Rio in 1992 concerns of climate change on mountains was addressed by policy makers with a special chapter in Agenda 2 which was followed by the UN General assembly marking 2002 as the ‘Year of the Mountain’ at the Global Mountain Summit and World Summit on Sustainable Development in 2002 (Schild, 2008). While awareness and evidence about climate change concerns in mountains is progressively increasing, there is still inadequate research and work in terms of policy response. International and national developmental agendas like poverty reduction, urbanisation and economic development issues are marginalizing the importance of safeguarding mountain ecosystems specially in developing nations like India, Nepal and Bhutan (Aryal et al., 2014; Barua et al., 2014; Maraseni, 2012).

In the case of India, spatial and sectoral policies at all spatial scales largely focus on building national or local economies and infrastructural development, with only a modest focus on social concerns. Majority of these policies fails to integrate concerns and location-specific issues of mountain regions and communities. In India, mountain communities in particular have historically experienced social, economical, political and cultural exclusion and empowerment. Adding the effects of climate change, communities in mountain regions have been and will continue to face drastic effects on their livelihood. For example, indigenous populations in the Himalayas depending on subsistence farming are facing problems due to climate change related changes in temperature and precipitation as well as those that depend on rapidly changing alpine habitats for medicinal plants, alpine grazing lands and forest products. It is therefore essential to design effective and location-specific policies in order to adapt to climate change in these regions, which should also include local knowledge and communities' perception to cope with climate vulnerabilities (Gippner et al. 2012; Picketts et al. 2013).

With the largest concentration of glaciers outside the polar region and feeding nine major rivers systems in Asia, the Hindu-Kush Himalayan range is one of the most important eco-regions of the world (Bajracharya et al., 2007). The Eastern region of Hindu Kush Himalaya is particularly important in view of climate change impacts because it is one of the most diverse temperate regions of the world with distinct eco-regions, biodiversity hotspots, grass lands and home to diverse socio-economic and ethnic communities (Salick et al., 2014; Schild, 2008). Livelihood of inhabited communities in these regions is largely dependent on different agricultural practices and surrounding natural resources. Consistent increase in overall warming, changes in seasonal patterns and decrease in annual precipitation has become a serious concern for rural and agriculture based communities in the Eastern Himalayan regions (Macchi et al., 2011). These mountain regions, like other eco-sensitive regions such as wetlands and coastal zones, have very distinct and unique problems due to climate change and therefore cannot be tackled with global or country level policy initiatives, but require independent assessment frameworks and action responses.

However, assessing climate change impacts in the Himalayan region has been challenging due to lack of significant historic data and crude assessment from current climate models that oversimplify the climate concern in these regions (Beniston, 2003; Schild, 2008). Researcher and international organisation are therefore focusing on improving methods of analysing climate concern of mountain regions and trying to explore impacts at finer spatial scales. Technological advancements such as availability of high resolution remotely sensing data has to some extent allowed improvement in understanding local climate and ecological processes in mountain region (Byg and Salick, 2009). However, knowledge about impacts on socio-ecological system is still ambiguous which makes mapping climate change vulnerability a difficult task.

We therefore base our studies in the district Darjeeling in the Eastern Himalayas which is facing severe problem due climate change and land use changes. Land use practices play a significant role in the livelihood of the people and also in determining the stability of the region with respect to landslide hazards. A significant portion of Darjeeling district is under forest cover while the lower ridges hilly ridges have been cleared for the cultivation of world famous tea plantations. Changes in land use patterns due to socio-economic factors are resulting in decrease in forest area, increase in agricultural activities related of tea and medicinal plantations and expansion of urban areas along the slope. Concurrently the changing climate is further exasperating the effects on land use patterns and deteriorate the fragile ecosystem of the region. The frequency of landslide, flooding and droughts has increased and the average annual temperature in the last 100 years has increased by 4˚C in the Darjeeling Hill areas (WBGov, 2012). The number of rainy days has increased from 155-135 to 160-140 days (WBGov, 2012). The soil and terrain of the region cause heavy runoff and erosion during the monsoon and water scarcity during the non monsoon season. In addition to these ecological problems, economic marginalisation, lack of basic facilities and unstable local government has made sustainable and planned development of the region very complex.

Therefore, in this study, an effort is made to explore the spatial vulnerability of climate change in selected sites in the Darjeeling District of the Eastern Himalaya, India. We also analyse the perception of people on climate change in the region and how it varies in extent and magnitude.

5.2 Data and method

5.2.1 Study Area

The study was conducted in the Darjeeling district of the state of West Bengal, India with special emphasis in six different sites for detailed analysis (mix of urban and rural areas at different altitudes) as shown in figure 5-1. Geographically, Darjeeling district of West Bengal is situated between 26° 31' and 27° 13' north latitude and between 87° 59' and 88° 53' east longitude with a total area of about 3149 sq. km. The area is bounded by Nepal on the west, Sikkim on the north, Bhutan on the north-east, Purnea district of Bihar abutting on the south and district Jalpaiguri of West Bengal on the south-east. The southern foothills are demarcated by a highly dissipated platform of terrace deposits extending along the east west axis. The elevation of Darjeeling district varies between 800 m to 3660 m above sea level with numerous high ridges and low-laying valleys

(Chaudhary et al., 2011). The annual rainfall fluctuates from 2000-2500 mm in the plains to 4000-6000 mm at the mountain region. There were distinct patterns of seasonal distribution of rain in the region. However, recently the amount and distribution of rainfall has been erratic which plays a very important role in the instability of slopes. The Darjeeling Hill area has been witnessing increase in number of days of high intensity rainfall within a short span of time resulting in increased number of landslides at different locations (Ghosh et al., 2012). According to the 2011 census, Darjeeling district has a population density of 585 inhabitants per square kilometre (1,520 /sq. mi.) with 60% of total population residing in urban areas. Its population growth rate over the decade 2001 to 2011 was 14.47%.

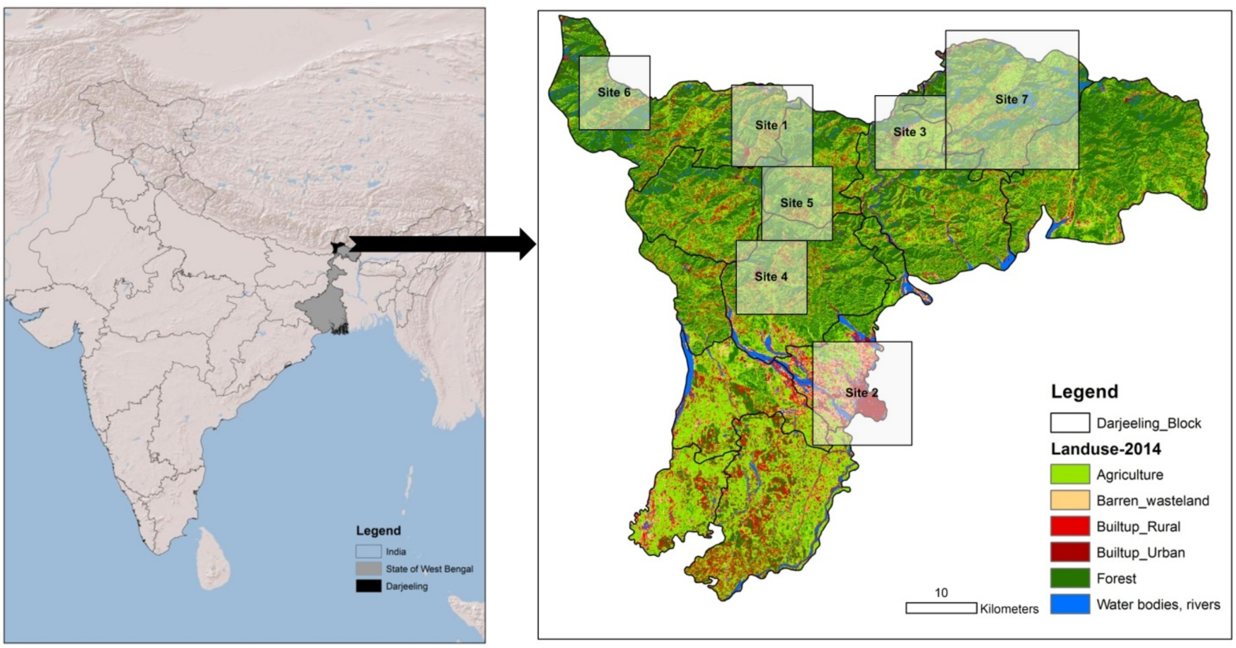

Figure 5-1: The study area Darjeeling district, India and land cover map 2014, and location of selected site for detailed analysis.

5.2.2 Method and Data

In this study we investigate two key concerns of climate change a) spatial patterns of climate change vulnerability and b) Perception of people to climate change impacts. To fulfil these objectives, secondary data was collected from government organizations, local NGO's and community social groups and primary data was collected from field work carried out between April to June 2014. It is to be noted that the vulnerability assessment is based upon the framework and methodological approach of chapter 4. The difference lies in the indicators used in the framework, which depends on the spatial setting of the study area.

Table 5-1: Socio-demographic profile of selected sites in the study area

Sites	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	Site 7
	Darjeeling	Siliguri	Kalimpong	Kurseong	Senchal Wildlife Sanctuary	Singalila National Park	Ghis and Leis watershed region of Kalimpong
Type(Urban /Rural)	Urban	Urban	Urban	Urban	Rural (Forest Villages)	Rural (Forest Villages)	Rural (Villages in interior region of Kalimpong block)
Number of town/Villages	Municipal town	Municipal town	Block level town	Municipal town	5 Forest villages	3 Forest villages	6 Villages
Elevation (m)	2,045.2 m	644 m	1,247 m	1,500 m	1067–1600 m	2400–3660 m	1,247- 2,200 m
Local climate	Temperature varies from 8˚C to 15˚C from winter to summer season. Summers are wet due to the monsoon rains from June to September	Chilled winds with a mean of 9˚C in winters and hot in summer with 35˚C mean temperature. Heavy rains during the monsoon season from June to September	Temperature varies from 8˚C to 30˚C from winter to summer season. Monsoons are severe, often causing landslides	Kurseong is warm and temperate, with temperatures varying from 10˚C to 21˚C winter to summer.	The temperature varies from 1.7˚C to 8.4˚C through the year. Frost is very common from December till March in areas above 2000 m. In the high ridges, some snowfall	Mean temperature varies between -20˚C to 15˚C. Average relative humidity varies from 83% to 96%.	Humid and subtropical with temperature varying from 4˚C to 27˚C. Average annual rainfall is 2030 mm.
Economic activities (Livelihood activities)	Tourism, small entrepreneurship, tea and spice plantations.	Small entrepreneurship, daily wage activities and tourism	Small entrepreneurship, daily wage activities and tourism	Small entrepreneurship, daily wage activities and tourism	Tourism, timber production and small or marginal farmers	Tourism, timber production and small or marginal farmers	Small or marginal farmers, tea and spice plantations
Socio structure	Majority of people with Nepali ethnic background with several sub groups. These groups have their own dialects and community based organization						

5.2.3 Secondary data

In order to investigate the climate change vulnerability, the vulnerability assessment framework proposed by Füssel and Klein (2006) is used in this study as in chapter 4. According to Füssel and Klein (2006), vulnerability is the result of three key components: exposure, sensitivity and adaptive capacity. In this study, vulnerability represents the current state of the socio-ecological system of this mountain region and describes the potential to experience harm from external and internal exposure due to the system's sensitivity and adaptive capacity.

As per Füssel and Klein (2006), exposure describes the nature and degree to which a system is exposed to significant climatic variations. In this study three indicators were selected to represent exposure component o f vulnerability assessment i.e. mean temperature change, change in average rain fall and number of rainy days. Data were collected from local metrological station source and secondary sources.

Sensitivity is the extent to which a system is affected, either adversely or beneficially by climate exposure and the effect may be direct or indirect. To assess sensitivity of the selected case study three main aspects were identified, namely, environmental, physical and socio-economic factors. Further under each aspect, indicators were selected using expert knowledge from discussions with local government organisation, NGO and semi-structured interview and discussion with different stakeholders (Table 5-2).

Adaptive capacity is the "ability of a system to prepare for stresses and changes in advance or adjust and respond to the effects caused by the stresses" (Engle, 2011; Smit and Pilifosova, 2003). The Adaptive capacity component were measured based upon three key aspects, namely, basic facilities, economy and social structure of the region. Each aspect of adaptive capacity components were further divided into indicators detailed in Table 5-2.

The assessment method was applied at two levels; one at blocks level (District subdivision) that is smallest administrative unit of local government and second at a household level from the interviews (as detailed above) in Darjeeling district. To evaluate vulnerability in either level, standardisation was conducted to convert original values of the indicator into a 0 to 1 scale to compare and aggregate the results of all the indicators. Indicators, aspects and components of the vulnerability assessment were combined by means of Spatial Multi-Criteria Evaluation (SMCE) method to understand spatial pattern of vulnerability. The final results of spatial pattern of vulnerability of climate change are presented in the form of maps that depict the spatial pattern of vulnerability to climate change ranging between 0-1.

5.2.4 Primary Data

We used semi structured interview and detailed questionnaire surveys at household level to understand the perception of people from selected sites (Appendix 6). In each site, focus group discussions and selected interview were conducted. The questionnaire were designed according to the study area and the vulnerability assessment framework based on (Füssel and Klein, 2006). It covered questions related to the three key components of the vulnerability assessment framework, namely, exposure, sensitive and adaptive capacity. For this study only people above 25 years of age were included in the survey to capture the perception of two generations. A total of 170 respondents were interviewed. Interviews were conducted in Hindi, English and Nepali with the help of an interpreter for the local area. Field work and household interviews helped to gain insight of the socio-ecological problems that the communities are facing and played a significant role to understand climate change vulnerability. People gave household information based on their daily experience, historic behaviour about the climate pattern and impacts on physical, social and economic sectors. People were asked about their perceptions of climate change on the different indicators tabulated in table 5-2 and the answers were recorded either as qualitative descriptive responses, as yes - no responses or as values on a scale of 1 to 5. Responses from the primary survey were categorized into exposure, sensitivity and adaptive capacity followed by standardization on a scale of 0 to 1 for statistical analysis. This information was used to assess the vulnerability (V) of each respondent at each location as Equation 1 (Metzger and Schröter, 2006)

$$V = f\{(Exposure), (Sensitivity)(Adaptive\ Capacity)\} \tag{1}$$

This is the same method of calculating vulnerability as used in chapter 4. Later on this information was structured to develop a vulnerability pattern of climate change within households and communities with the help of descriptive analysis.

Table 5-2: Indicators used to measure climate change vulnerability.

Vulnerability	Aspects	Indicator	Source (Ref)
Exposure	Climate variables	Increase in summer and winter temperature	(Hübler et al., 2008)
		Changes in pre-monsoon and after monsoon	(Rannow et al., 2010)
		Increase in days/year with heavy rain (RR >30mm)	(Rannow et al., 2010)
Sensitivity	Environmental	Land use change	(Pielke et al., 2011)
		Area under forest or wild life protected area	(Pielke et al., 2011) (Mundoli et al., 2014)
		Soil type and slope	(Mondal et al., 2014)
		Source of drinking water and quality	(Delpla et al., 2009; Meuleman et al., 2007)
		Distance to the water source	(Meuleman et al., 2007)
	Physical	Road condition and accessibility	(Szendrő et al., 2014)
		Type of housing material	(Habitat, 2011b)
		Type of basic services available	(Barua et al., 2014; Habitat, 2011b)
		Landslide zone and frequency of landslide	(Huggel et al., 2012)
	Socio-economic	Accessibility of public health centre	(Frumkin et al., 2008)
		Type and time of migration	(Baca et al., 2014; Black et al., 2008)
		Children younger then 6 year	(Bartlett, 2008; Han and Foltz, 2013)
		Bank accounts	(Lung et al., 2013)
		No of fair price shop	(Habitat, 2011b)
Adaptive Capacity	Basic facilities	Clean drinking water connection	(Banks et al., 2011; De Sherbinin et al., 2007)
		Efficient cooking fuel	(Mitigation, 2011)
		Accessibility to pubic transport	(Banister, 2011; Szendrő et al., 2014)
	Economic	Housing ownership	(De Sherbinin et al., 2007; Dodman and Satterthwaite, 2008)
		Asset ownership	(De Sherbinin et al.,

			2007; Dodman and Satterthwaite, 2008)
		Local government or communities based organisation	(Agrawal, 2010)
		Awareness and knowledge of different policies and scheme run by local government	(Baca et al., 2014)
	Social	Level of education	(Holsten and Kropp, 2012)
		Quality of technical assistance	(Holsten and Kropp, 2012)
		Accessibility of media	(Sampei and Aoyagi-Usui, 2009)

5.3 Results

The results of the spatial assessment of climate change vulnerability for the Darjeeling Himalaya are first presented under the components exposure, sensitivity, adaptive capacity and overall vulnerability at block level. In addition to it perception of people were used to evaluate site wise potential vulnerability. The results of vulnerability assessment application are presented below.

5.3.1 Spatial vulnerability pattern of climate change at Block level

5.3.1.1 Exposure

According to this study the majority of the blocks in Darjeeling district were found under very high exposure from different climate stimuli. About 57% of the total area was seen to be facing severe exposure. The results of the exposure component were based on climate stimuli like mean temperature change, extreme events of precipitation and annual precipitation change. The result of exposures showed stronger effects in the north and north-western region and central region of Darjeeling district as shown in figure 5-2. Increased number of days with intense precipitation (RR > 50mm) and change in mean temperature were the key indicators that influenced the exposure component. It was also observed that there was persistent increase in mean temperature in entire Darjeeling district from .5 ^{o}C to 1.5 ^{o}C for the last fifteen years especially in the blocks located in the northern, western to southern region of Darjeeling district. Some of the reasons for this change are extensive land use change in term of deforestation, intensive agriculture farming and physical development.

Majority of block of Darjeeling district were observed to be facing increased number of days of high intensity precipitation (>50mm) that is likely to make the district more vulnerable to extreme events like landslide in the higher elevation, sink zones and flooding in the plains. Blocks in the central and eastern region were severely affected by intensive rain in the past decades. These regions are also more prone to landslide because of soil type, sink zones, fault line and extreme climate events (Mondal and Maiti; WBGov, 2012). While, there was overall increase in annual average rainfall, the northern and central block of Darjeeling district showed decrease in annual average rainfall. Fast runoff during the monsoons, together with lack of rainfall in the non monsoon seasons results in drought conditions in large parts of Darjeeling district. As a result during the lean season between January to May, there is scarcity of clean water, which is exasperated by skewed distribution services and losses from dilapidated old British water supply system (WBGov, 2012).

5.3.1.2 Sensitivity

Analysis of the indicators of the sensitivity component showed that about 50% of the total area of Darjeeling district was sensitive to the effects of climate change. Spatial distribution of sensitivity component (Figure 5-3) showed that the Blocks in eastern to northern region of Darjeeling district were more sensitive to different climate stimuli than the southern regions. Most of the blocks were observed to be more sensitive to changes in social and physical aspects than to natural aspects. The overall sensitivity of the district was largely determined by the social and physical aspects. The social and physical sensitivity to climate change was maximum in the eastern regions like Kalimpong I, II and Gorubathan blocks. Results of social and physical aspects were based on indicators such as health, infrastructure, people at risk, banking facilities, road infrastructure, housing quality and risk zones. Spatial distribution of social aspect of sensitivity showed that approximately 45% of the total area, mainly in the eastern region, was highly affected by social factors. About 33% of total area of Darjeeling district showed high levels of risk due to physical factors. About 50% of total areas was found to show medium levels of sensitivity due to natural factors such as climate stimuli and human intervention. The overall sensitivity analyses showed that mountain region of Darjeeling district are more sensitive to the effects of climate change than plains. Mainly because in these regions people are either socially vulnerable in term of lack of basic facilities, accessibility, physical infrastructure and poverty, or because their livelihood depends on natural ecosystem and agriculture.

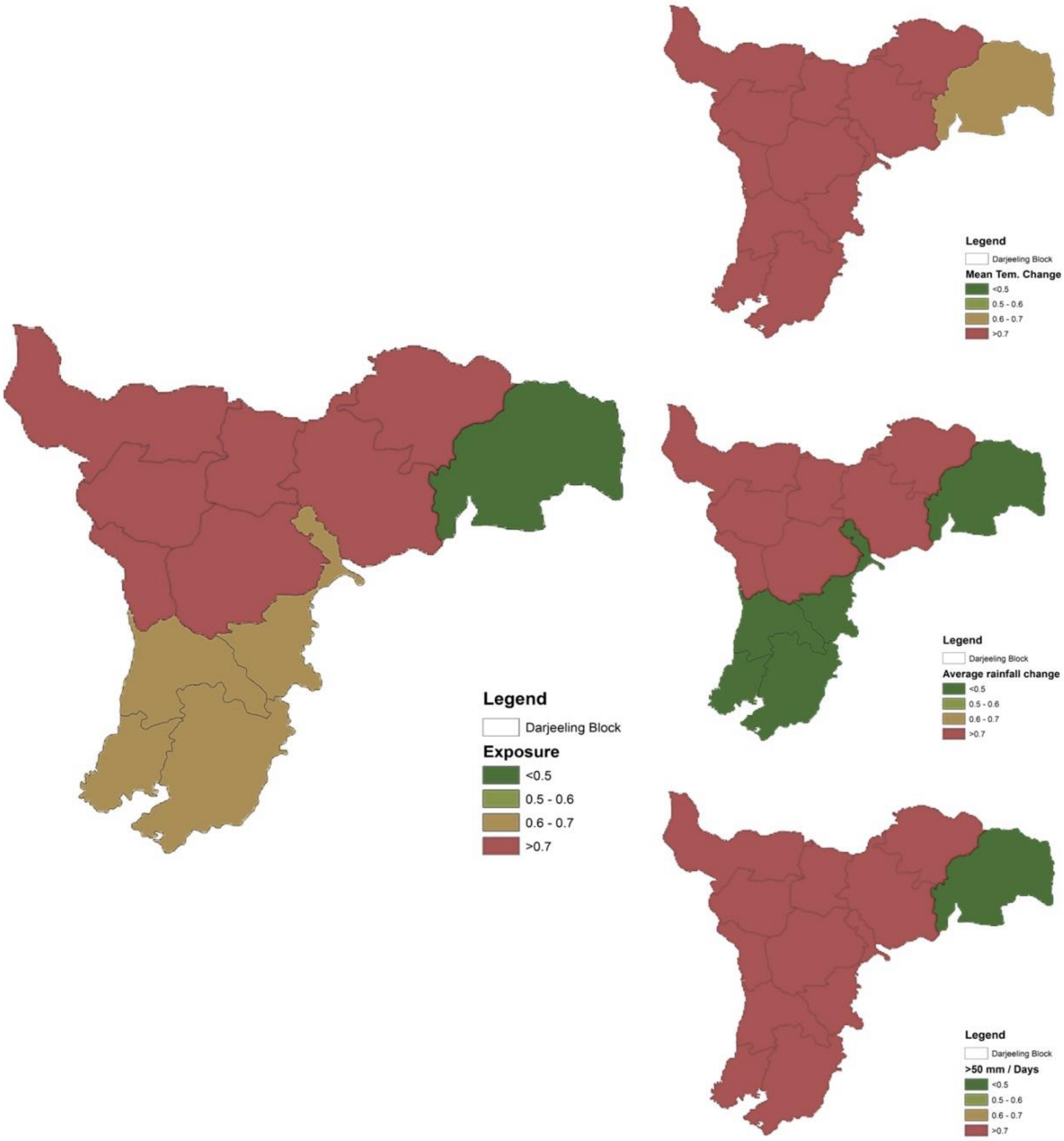

Figure 5-2: Spatial distribution of the exposure components of climate change vulnerability and aspects of exposure component. a) Exposure a1) Mean temperature a2) Rainfall a3) Number of days > 50 mm rain.

5.3.1.3 Adaptive capacity

The adaptive capacity for different blocks of Darjeeling district were measured based on three key aspects mainly basic facilities, economics and social aspects. Figure 5-4 shows the block wise spatial distribution of adaptive capacity. The overall adaptive capacity of Darjeeling district was observed in a low to medium range from 0.2 to 0.55. It was found that southern and eastern blocks of Darjeeling district had very low adaptive capacity compare. Adaptive capacity was also found higher in those regions that had active economic activities like tea production, cash crop production, better social infrastructure or social integration like awareness, participation and higher education levels. Most blocks in the district seem to require urgent attention to drastically improve the basic facilities and economic activities. Most rural areas were observed to have very low accessibility by roads. In addition decrease in agriculture and tea production because of erratic climate changes has resulted in loss of jobs opportunity and livelihood option, forcing people to migrate to towns and cities.

5.3.2 Overall vulnerability pattern of climate change in Darjeeling district

The overall spatial pattern of vulnerability of Darjeeling district to climate change is presented in figure 5-5. Blocks of northern and eastern region of Darjeeling district were observed to be facing high magnitude of vulnerability to climate change. These results are because of the high influence of the exposure and sensitivity components in these blocks. However, it was also observed that the overall adaptive capacity was low for the entire district. About 35% of total areas of Darjeeling district need urgent attention in term of adaptation response to climate change. Most blocks at high altitude, like Kalimpong I and II, Darjeeling Pulbazar and Rangli Rangliot were observed to be most vulnerable to climate change.

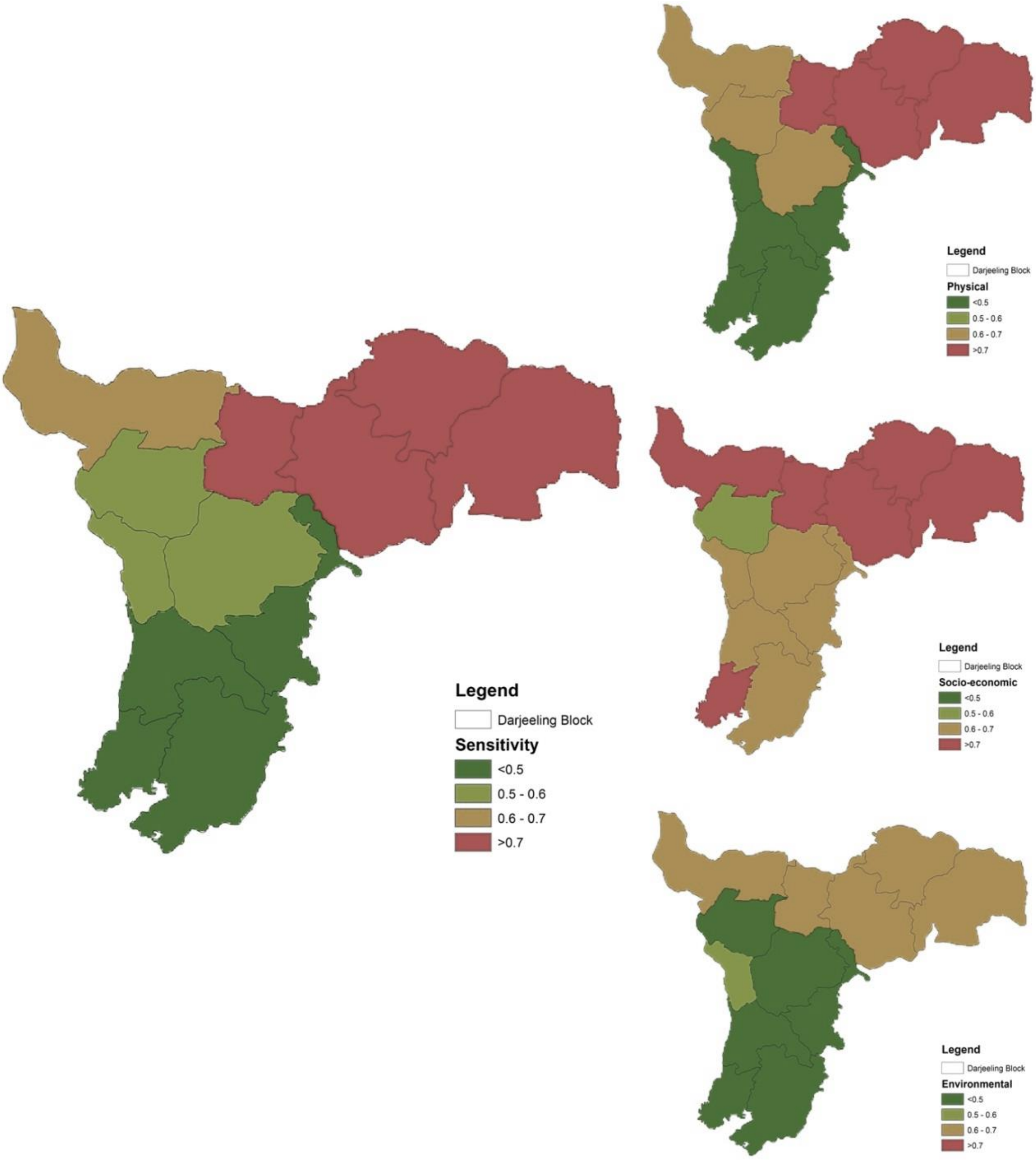

Figure 5-3: Spatial distribution of sensitivity component of climate change vulnerability and aspects of sensitivity component b) sensitivity b1) Physical aspect b2) Socio-economic aspect b3) Environmental.

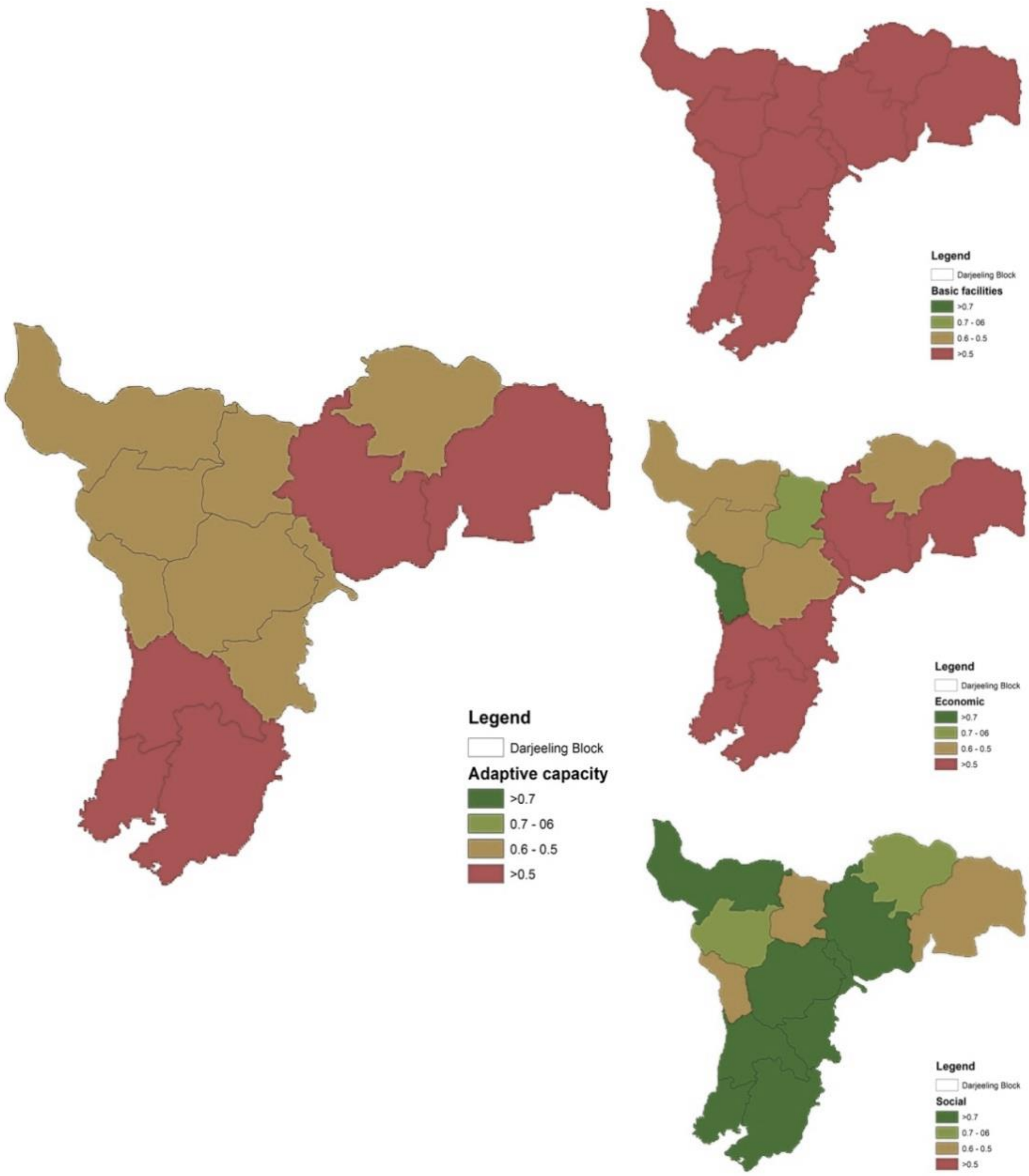

Figure 5-4 : Spatial distribution of adaptive capacity component climate change vulnerability and aspects of adaptive capacity component c) Adaptive capacity c1) Basic facilities aspect c2) Economic aspect and c3) Social aspect.

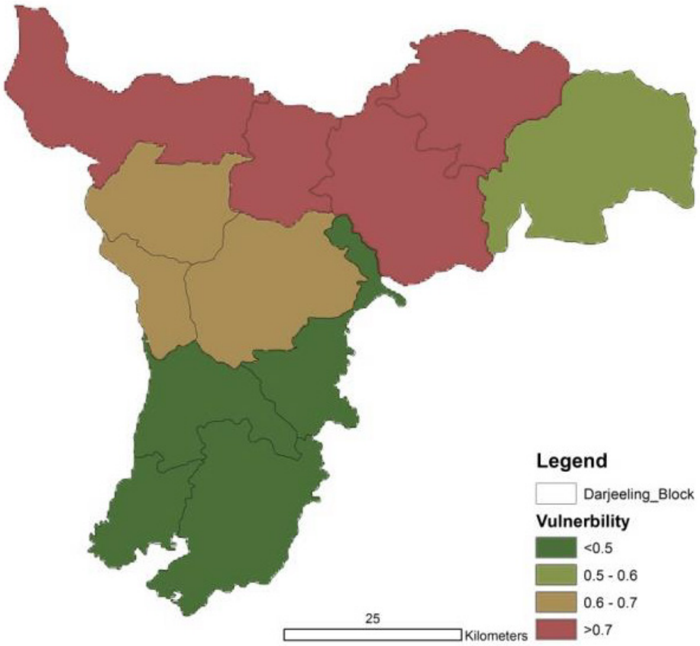

Figure 5-5: Spatial distribution of vulnerability pattern to climate change in Darjeeling District

5.4 Spatial vulnerability pattern of climate change at site level from perception of people

5.4.1.1 Exposure

The results from the interviews showed some interesting results. The perception of people towards indicators in the exposure component like average temperature change, total number of high intensity rain days and average annual rainfall change showed an increase in all most all blocks in the Darjeeling district. Historic and meteorological data from the selected sites confirmed that there were changes in the trend of climate variables (IMD, 2015). Group discussions and questionnaires revealed that the people of the region observed significant changes in recent climate pattern for example changes in seasons, erratic climate events, drought in summers seasons as well as decrease in annual precipitation and increase in intense rainfall days.

The survey results showed sites 5, 6 and 7 people perceived high exposure to climate indictors as compare to the other sites (Figure 5-6). These sites were located mostly in medium to high altitudes with most of the area under forest and agricultural land use.

Livelihoods of the people of these sites are dependant on agriculture. Considerable change in climate variables like temperature and rainfall were having high impacts on the production of agriculture commodities and local ecosystem services. Landowner and farmers were experiencing significant loss in tea, cardamom and local agriculture production and change in agricultural productivity in the past decade. However people living in or near urban areas perceived less exposure to direct climatic changes. They perceived changes as second order impacts of climate change like change in seasons that impacted local tourism, availability of water in summer season and observed landslides events during high intense rain days.

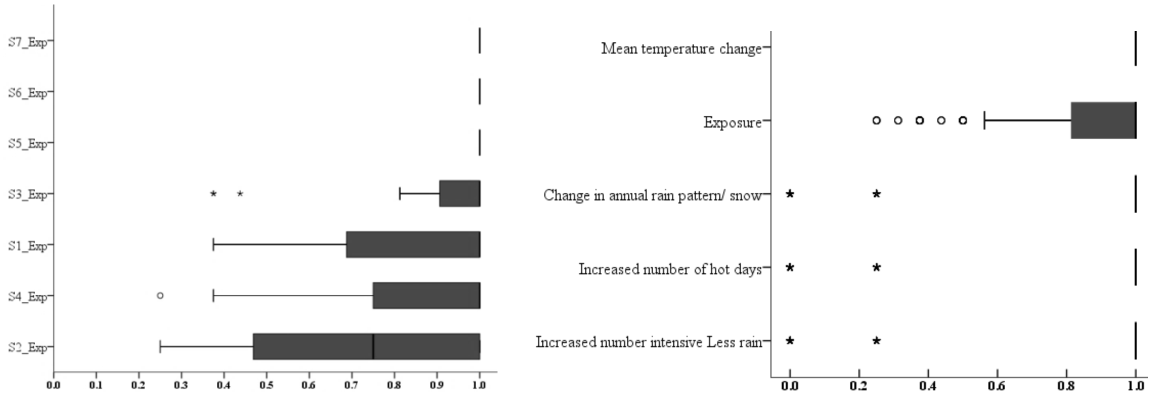

Figure 5-6: Site wise exposure component assessment and perception of local people on key sensitivity indicators

5.4.1.2 Sensitivity

About 70% of total respondents were observed to be highly sensitive to climate exposure. 100% sampled interview from site 5, 6 and 7 fell into the high sensitivity grade (Figure 5-7). These are also those sites that were observed to have a high exposure to climate variables. It was observed that site 2 was least sensitive to climate exposure. This site was located at a low altitude and foothill of Darjeeling district. The highly sensitive sites according to the perception of people were those that lacked accessibility to health and basic facilities, showed drying of water source, incurred migration because of climate change, showed major land use changes, high unemployment, and low physical infrastructure. Site located in or near urban areas were found to show medium sensitivity and observed to have better accessibility to physical, social, basic infrastructure and market opportunities.

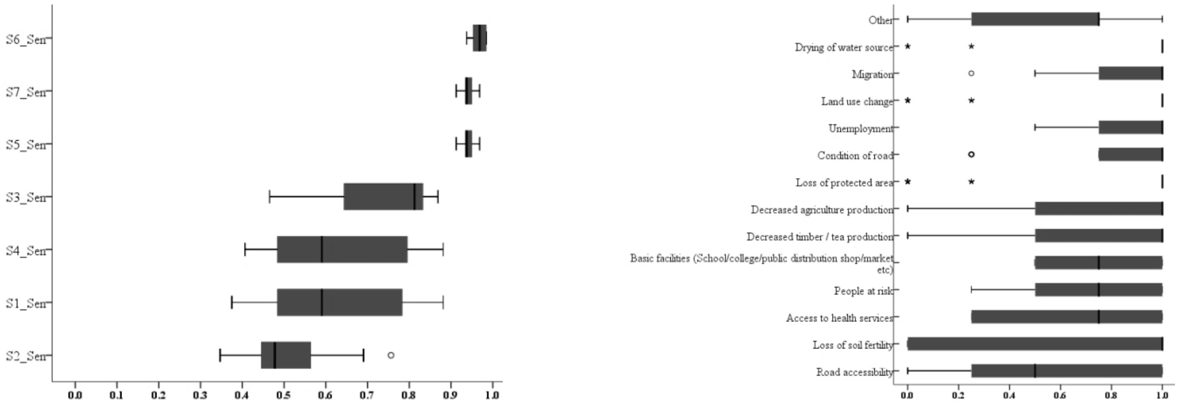

Figure 5-7: Site wise sensitivity component assessment and perception of local people on key sensitivity indicators

5.4.1.3 Adaptive capacity

The adaptive capacity for different selected sites were measured based upon three aspects namely, economy, basic facilities and social aspects. Household from site 6, 7 and 5 were perceived to have the lowest adaptive capacity (Figure 5-8). About 50% of the total sampled household showed low to medium adaptive capacity. Some of reason for having low adaptive capacity to these regions was the local government. Currently local governments and institutions are undergoing major transformation to provide basic facilities and infrastructure to the sites located in rural areas. Due to the political instability in the region, government institutions at rural level have ceased to obtain financial as well as administrative assistance from the district and state level. Sites in the foothills like Siliguri, Kurseong were found to having better adaptive capacity than other regions due to urban development and livelihood opportunities.

5.4.2 Perception of people and overall vulnerability at site level

The result of the overall vulnerability indicates that about 61% of the total sampled households were highly vulnerable (Figure 5-9 and 5-10). Exposure was the key component of high climate change vulnerability values in most sites. People living in the higher altitudes seem to be facing increased number of hot days, mean temperature change, increased number of intense rain days. Communities at the foothills of Darjeeling hills noted increase in the dry season, fluctuation of pre-monsoon and after-monsoon rains and increase in mean temperature. High vulnerable site also perceived greater sensitivity to climatic changes resulting in loss of agriculture production and ecosystem services causing negative repercussion on the development of communities. These sites had showed low levels of adaptive capacity because majority of households had low level of awareness, lack of employment opportunities and most importantly lack of participation at any stage of policy preparation or even in local government.

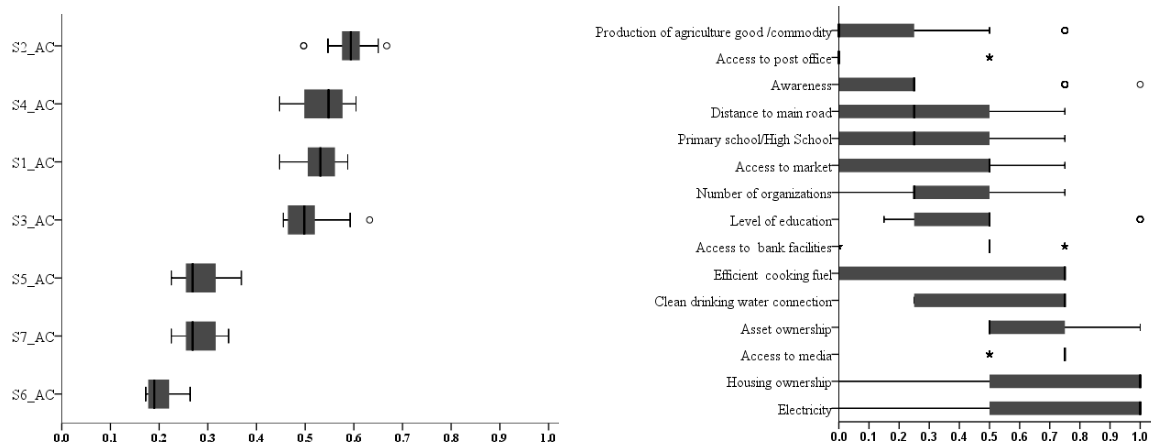

Figure 5-8: Site wise adaptive capacity component assessment and perception of local people on key adaptive capacity indicators

5.5 Discussion

Himalaya is one of the most complex socio-ecological systems of the world. It is among the youngest mountains of the world and home to key biodiversity hotspots and critical eco-zones of the world (Chaudhary et al., 2011; Myers et al., 2000). Even small disruption and disturbance from external sources and climate variables has a drastic consequence on the entire socio-ecological fabric. Intuitively it is conceivable that the district Darjeeling, as one of the most disturbed and degraded parts of the Himalayas, is likely to be affected by climate change. Also local communities have already started observing detectable changes in the patterns of climate variables and its impact on agricultural production. However the geographical and demographical characteristics of the district, with poor accessible landscapes, difficult terrains, scattered villages and poor infrastructure, makes scientific research with adequate data a near impossibility (Mukherjee, 2013). In this research we therefore attempts to integrate the two most informative sources of information in the form of remote sensing data and knowledge from local communities to understand the vulnerability of the region and their repercussion on local livelihood and well-being.

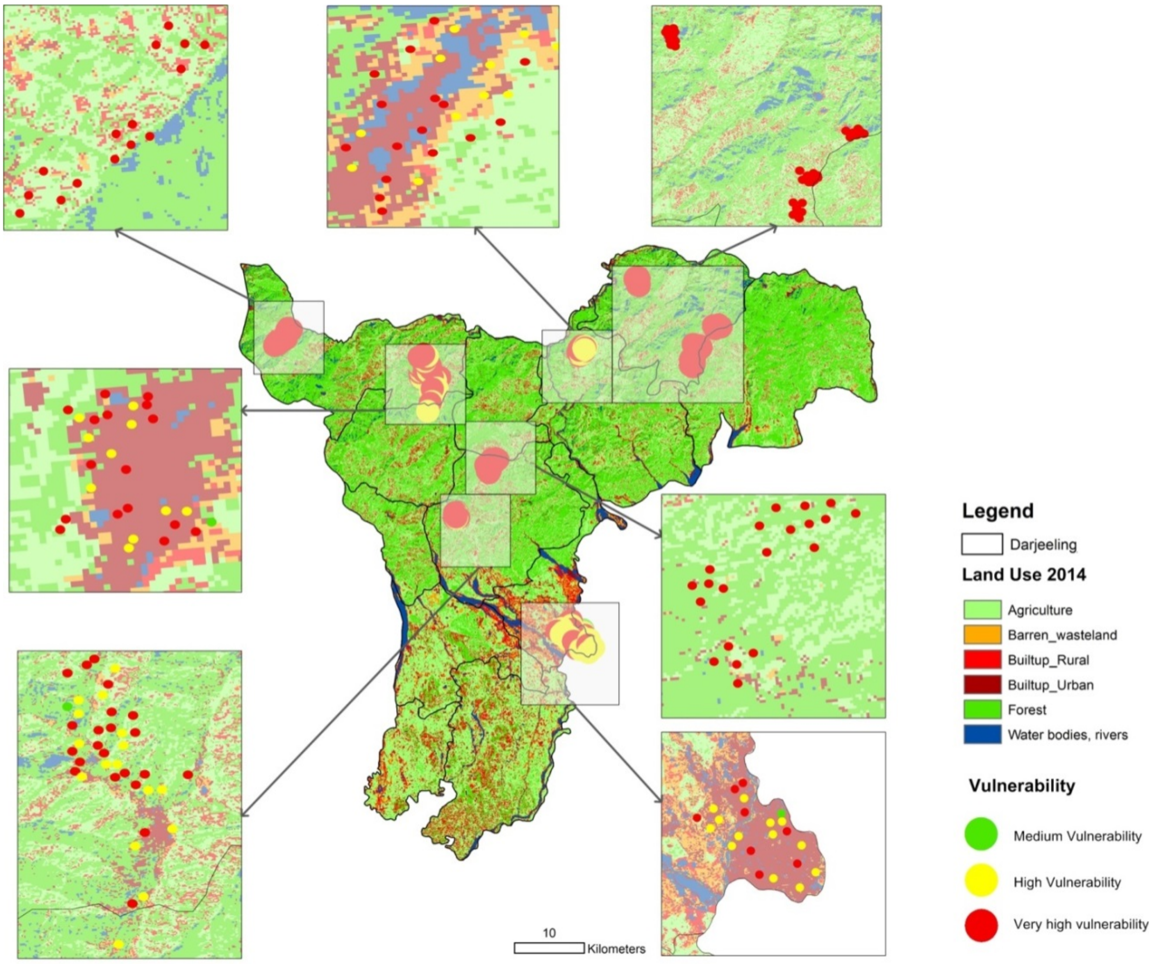

Figure 5-9: Site wise spatial vulnerability pattern to climate change among communities in Darjeeling District

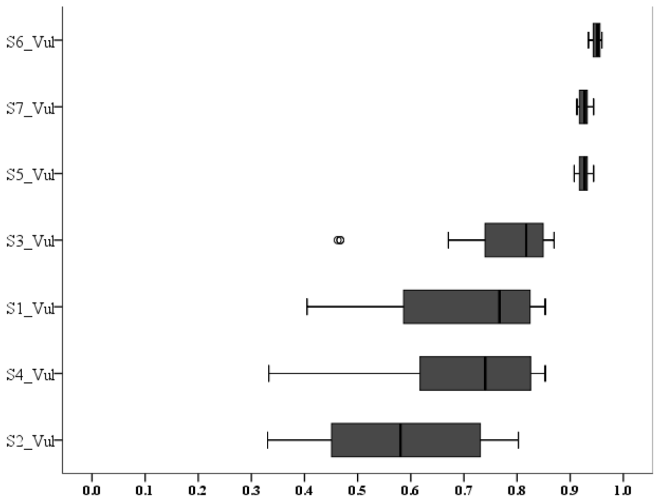

Figure 5-10: Site wise vulnerability assessment by local people perception

The remote sensing data as well as detailed data from government organization were used to assess vulnerability pattern of climate change at block level, using scientific frameworks to evaluate exposure, sensitivity and adaptive capacity of the region. The research conducted is highly suitable for this type of terrain and is potentially an improvement on other frameworks of research because the study effectively integrates empirical evidence of social as well as ecological nature.

Darjeeling district is constituted of about 73% area under hills and 27% area under plains. Geography, elevation and climatic variables play an important role in social and ecological aspect in Darjeeling district. Findings of this study show that majority of Darjeeling subdivision (Block) are experiencing high vulnerability to climate change especially is the hilly regions of the district namely, Kalimpong I and II, Darjeeling Pulbazar and Rangli Rangliot block of Darjeeling district. These are the blocks that have high sensitivity to physical, social and ecological aspects. The population explosion and floating tourist influx in the region has dramatically increased the per capita resource demand. This has resulted in over exploitation of natural resources such as forests, water and land for agriculture resulting in hydrological imbalance, soil erosion and socio ecological disparity. This provokes micro climatic changes, devastating effects in the event of extreme climatic conditions as well as poor adaptation capacity due to economic backwardness. About 35% of total areas of Darjeeling district needs urgent attention in term of adaptation response to climate change, majority of which lies in high altitudes, rural and marginalised communities. The Blocks Kalimpong I and II, Rangli-Rangliot, Kurseong, Bijanbari and Gorubathan are particularly susceptible to landslides. In these blocks large areas of land have been cleared for commercial agriculture (rather than the traditional subsistence farming) to grow root vegetables like potatoes, ginger, onion and cardamom. The crops are harvested just after the monsoons, affecting soil cohesiveness. Large bursts of rainfall during the off monsoon seasons, due to changing climatic conditions, makes these areas prone to erosions and landslides. Blocks lying in the foothills such Matigara, Naxalbari, Phansidewa, Kharibari are less prone to climate vulnerability partly because they are less exposed to extreme climate changes and have low sensitivity to climate stimuli and partly because the economic development in the region makes them more resistant. In the absence of proper policies for development, physical growth in the district has been very erratic, with high density housing on acute slopes, some high rise building and slums in urban areas (Mukherjee, 2013). As this region lies in the seismic zone IV, the buildings are in great danger to earthquakes as well as climate related events such as cyclones, landslides, cloud bursts and glacial lake outburst flooding (GLOF) (Chhetri and Tamang, 2013).

One of the key approaches of this study was to integrate knowledge and perception of indigenous people and communities on climate concerns which have been lacking in earlier studies on climate change research in mountain region for developing policies (IPCC, 2001; Parry, 2007b; Salick and Ross, 2009). Local communities amass knowledge on the changing climate and the means to cope with them (Chaudhary and Bawa, 2011). This information when integrated with scientific knowhow and other databases can be used to device socially acceptable mitigation and adaptation policies. Perception of people and communities analysed in the study showed large percentage of communities in the district are experiencing high vulnerability to climate change albeit in different measures and as different stressors. The information from selected sites confirmed that phenomenon's such as changes in duration of season, less snowfall on the mountain, rise in temperature in winters and hot summers were occurring, and that these were already acknowledged in previous studies (Chaudhary et al., 2011; Patra et al., 2013). Communities located in Kalimpong I and II blocks also confirmed extreme events of climate change like cyclones, unpredictable rainfall and its impact in the form of landslides, loss of physical asset, human life, unaccountable ecosystem services and biodiversity (Kumar, 2012). Unlike the results from the block level analysis, communities in the foothills also affirmed to be experiencing climate exposures like altered patterns of rainfall, increase in annual rainfall, increase in number of hot days, dry spell in summer season and flooding in the monsoon season. At sites located in rural and ecological sensitive regions like Singalila National Park, Senchal Wildlife Sanctuary and Kalimpong regions and blocks lying in the high altitudes seemed most effected by climate change. Economic and social activities in these sites are mostly agriculture and ecosystem based which makes even minute changes in the climatic condition as reason for concern. For example, large parts of this region have an economic base in production of tea, spices and vegetables. Good quality of tea and spices account for a very good value in the national and international market and in the last decade the production has been severely hampered. According to the evaluation of the perception people as well as views of local experts from tea research board in Darjeeling, the production and quality of tea has gone down. Large areas of land under spice production is not suitable anymore and had to be abandoned because of degradation of tree plantation which provide the shade and soil cohesion required for spice plantation (Patra et al., 2013).

The interviews also revealed that for the communities in the rural sites protecting their immediate physical and ecological space is most important for their livelihood and day to day survival. However for people in urban areas the needs were indirectly related to the effects of climate change in the form of tourism, tea production and infrastructure. Communities did confirm that livelihood was linked to agricultural production with the weather patterns but most people failed to associate it to the effects of global climate change. People also described how changes in local climate were having impacts on the health. People have become more vulnerable to heat waves, mosquitoes, flies and pests which have increased in the high altitudes of Darjeeling district. Number of cases of malaria is increasing in the hills, that used to be predominant only in the plains (Chaudhary and Bawa, 2011; Sharma et al., 2009).

Results of this study show that non climatic factors also have significant effects on the evaluation of climate change vulnerability. Social, physical and cultural structure of the communities in the mountain were found to be linked the vulnerability of particular gender, people and communities than other (Adger et al., 2013; Thwaites et al., 2014). People and communities from high attitude and rural setting are marginalised in nature and experience interlocking between internal and external stresses like population migration, environmental degradation, market failure, decreased agriculture production and political insatiability making them more vulnerable (Morton, 2007). However communities located in the urban areas are facing issues like shortages of water in summer season, flooding during monsoon seasons which have significant impacts on tourism. At the same time urban areas are becoming dense and expanding. Urbanisation is forcing hazard due to land use change that in turn impact the local climate (Chhetri and Tamang, 2013; Mell and Sturzaker, 2014).

The adaptive capacity of the district is greatly affected by physical infrastructure like roads, electricity and water. People have low accessibility to market, education institution, awareness and government institution. Decision making and local government institution are weak or missing completely. People and communities from different sites are coping with climate concern within their capacity or with the help of local self help groups which have only limited impacts. Development of effective adaptation response and its implementation by local institution needs a revival.

In India the National Mission for Sustaining Himalayan Ecosystem (NMSHEs) is responsible for research and development of climate change impacts and is one of the missions of India's National Action Plan on Climate Change. The district Darjeeling also comes under the purview of this mission, which is responsible for conducting extensive research, evolve suitable management and policy guidelines and work with different stakeholders to implement these guidelines. The results of this study highlights the potential of understanding the spatial mapping of vulnerability assessment by integrating social, economic and ecological aspects of the selected case study. These results can then be utilised to identify critical areas of concern and devise adaptation policies such as expanding current developmental policies to include climate change concerns, build institutional capacity of governing bodies and local communities and spreading awareness. Most studies on climate change in the Himalayas focus on snow, vegetation, tree line, soil and fauna which are conducted under very broad scales, ignoring the cultural and social dimension of the mountain communities. There is serious urgency for interdisciplinary studies such as this that integrates climate science knowledge and perception of communities; the results of which can be accessed by local institutions and government bodies for climate change mitigation and adaptation response.

Chapter 6

This chapter is based on: Kumar, P., Geneletti, D. (in preparation). Assessing the effect of ecosystem based policies for adaptation to climate change in Darjeeling Himalaya.

6 Assessing the effect of ecosystem based policies for adaptation to climate change in Darjeeling Himalaya

6.1 Introduction

Climate change is inextricably linked to the ecosystem and livelihood of communities living in mountain regions (Kotru et al., 2014). With extreme climatic condition, varying topography, changing ecological zones and related microclimates, even slight change in temperature or precipitation patterns in the region drastically effects the fragile balance of the ecosystem and the communities dependent on them (Grêt-Regamey et al., 2012; Kotru et al., 2014; Schröter et al., 2005). In addition, mountains are biodiversity hotspots and provide key natural resources such as fresh water, forests products and minerals for people living in the region or outside it (MEA, 2005; Ten Brink, 2011). Such is the case also in the Indian Hindu Kush Mountains, where communities have historically been backward with excessive dependence on agriculture, pasturelands and forests. The changing climate in the region is already affecting their livelihood and they have started facing impacts of rising temperature, shifting seasons, water availability, shift in tree line to higher altitude etc. (Beniston, 2003; Chaudhary et al., 2011; Salick et al., 2014). Thus livelihood practices in the region are closely related to the availability and health of ecosystem services like water, energy, forest products, crops, habitat quality and tourism.

It is therefore ironic that the increase in per capita resource demands are resulting in degradation and over exploitation of the natural environment, leading to extensive loss of ecological habitat and ecosystem services (MEA, 2005; Willemen et al., 2013). This initiates a vicious cycle where communities degrade the natural environment and as a result further exasperate the affects of climate change vulnerability (Field and Van Aalst, 2014; UNISDR, 2011; Welle et al., 2012). Land use conversion and forest and soil degradation are among the most important factors affecting vulnerability to climate change in the region (Rao and Pant, 2001; Semwal et al., 2004; Upadhyay et al., 2005; Xu et al., 2009). Large parts of the region are in transition stages adopting new technology, urbanization and foregoing self subsistence living for open economies (Upadhyay et al., 2005). Increase in agricultural population in the region in resulting in conversion of forest and waste land for agriculture and is also putting undue pressure on forests for fodder, fuel wood and timber (Bajracharya, 1983; Silwal, 1995). It is therefore urgent that appropriate measures in the form planning mechanisms are put into place that regulates and monitors land use change in the region. Spatial planning is the main policy instrument that can affect the conversion and conservation of ecosystem services of a region (Geneletti, 2013). If such measures are not implemented now, the effects on this fragile ecosystem could be irreversible and far reaching.

To understand these dynamics between climate change vulnerability, ecosystem services and planning policies, we base our studies in the eastern part of the Hindu Kush Himalayas. The study area is located in two small watersheds, namely, Ghis and Leis, within the interior of Kalimpong subdivision, in the district of Darjeeling, where changes in land use and forest degradation has been emphatic and the consequent affects of climate change confirmed (Mor, 2013; Mukherjee, 2013). The district Darjeeling is under the environmental jurisdiction of the state of West Bengal in India. The West Bengal State action plan on Climate change (under the National Action Plan on Climate Change, India) designates the Darjeeling district as a priority area and one of the two most vulnerable regions of the state. A somewhat detailed plan does exists at the state level on how to make adaptive strategies, however there are two main problem with these plans: 1) Plans made at national and state level does not seem to be implemented at district/city/village level. The unstable government in the region as well as lack of proper funding has resulted in a defunct plan that cannot be availed by the local people. 2) Plans for conservation of the region are still based on meeting high demand of agricultural products (such as tea and spices) to cater the global demand, are engineering based adaptations strategies (such as building reservoirs and fortifying land slide prone areas) that will further change the ecosystem and are high cost measures. It is therefore required that alternative effort are implemented that will include scientific vulnerability assessment, environmental management and land use planning policies to safe guard the ecosystem of the region. In this respect ecosystem based response actions are becoming one of the most effective alternative policy responses to climate change among international and national policy makers (Colls et al., 2009; Langridge et al., 2014). Ecosystem based response action to climate change focus on restoration of natural resources and ecosystem to increase the adaptive capacity of communities and decrease the sensitivity to climate exposure with an aim to achieve resilient development (Estrella and Saalismaa, 2013; Langridge et al., 2014).

In this study we try to understand how ecosystem services based adaptation responses through spatial planning practices can increase adaptive capacity of mountain communities and address climate changes issues. We analyse a bundle of ecosystem services in two future land use scenarios. Scenario analysis to compare the results of conceptual planning practices is common in ecosystem based studies and has been made popular by the Millennium ecosystem assessment (Geneletti, 2013; MA, 2005). Scenarios are developed by proposing alternative policies (to the current status) regarding land use zoning , forestry practices, agricultural practices, economic and physical development (Geneletti, 2013; Polasky et al., 2011). The main objectives of the study are 1) Analysing if the existence/non existence of policies based on ecosystem services effects land use change in the study area 2) Evaluating how the existence/non existence of policies will effect specific ecosystem services through scenario analysis 3) Analysing and discussing how specific ecosystem based policies aid adaptation to climate change and how they can be included in current planning practices.

6.2 Case study and Method

6.2.1 Case Study

The study area is located in two small watersheds namely, Ghis and Leis, within the interior of Kalimpong subdivision, in the district of Darjeeling with detailed study of 6 villages (Figure 6-1). A socio demographic profile of each village is presented in the Table 6-2. Ghis and Leis watershed comprises of an approximate area of 11400 hectares which is governed by gram panchayats (local level governing body), the forest department and tea boards. The highest point of the watershed is in Lava (2138 metres) located at north-eastern part and the lowest point is in Patharjora (165 metres). Climatic condition varies from tropical to temperate. The major second order streams within the watershed are Geet Khola, Chamong Khola, Dewrali Khola, Dabling Khola, Reon Khola and Nimbong Khola. The upper ridgeline starting from Lava till Lolaygoan is an evergreen forest with exotic pine vegetation. Besides, there are several patches of forest scattered within the watershed subject to rapid deterioration due to several anthropocentric pressures. Most of the established and emerging towns are located on the ridgelines. Besides the forests at upper and the lower ends, vegetation coverage in the middle areas are almost nil, making the place very unsuitable for habitation. Most of the villages are remote and located near the bottom of the valley. Majority of the population is tribal and depends mostly on agriculture, cattle rearing and forest products. Villages are scattered and remote with many of them lacking basic infrastructures like roads, electricity, water supply, health centres, banks and schools. Due to highly scattered habitation and rough topography, only a few civil societies have reached out to these communities. In the last few years this area has been experiencing the impact of climate change on agricultural production and extreme events like landslide, flooding and seasonal drought. Pressure from national and international market to grow species and tea has brought changes in land use and land cover of the study area resulting number of environmental issues like water scarcity, habitat loss, soil erosion and agriculture production.

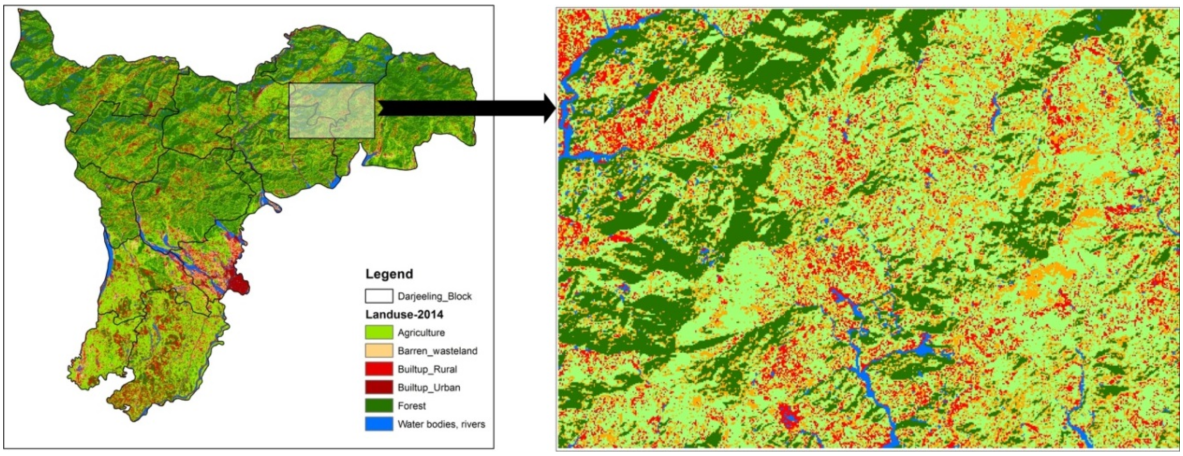

Figure 6-1: The study area Ghis and Leis watersheds, Darjeeling district and land cover map 2014.

6.2.2 Method

The method and results in this study are divided into three main sections. First, we used remote sensing data to map the land use patterns and based on scenario analysis we mapped predictions for change. Second, ecosystem services were evaluated considering different future land use scenarios. Thirdly, we conducted a detailed questionnaire survey to understand the socio-economic condition of the communities in the region, their land use practices and effects of climate change.

6.2.2.1 Land use change and scenario analysis

Land use change for past and current year was analysed through geo-spatial modelling in remote sensing and GIS. To prepare the basic inputs for the land use scenarios development, the base used were Landsat satellite images (2001 and 2014) from the official website of US Geological Survey (USGS). Map Projection of the collected satellite images is Universal Transverse Mercator (UTM) within Zone 46 N–Datum World Geodetic System (WGS) 84 and the pixel size is 30 m. Five land cover types were identified namely forest, agriculture, water, waste land and built-up to understand land use change pattern.

Future land use scenarios were mapped using Land Change Modeler (LCM) tool implemented in the software package IDRISI TERRSET (Eastman, 2009; Geneletti, 2013). The package allows the input of constrains and incentives of land use transitions as well as input of specific local policies on forest, agriculture and physical development. Two scenarios were envisaged considering two different approaches in land use policies:

1) ***Business as usual (LU-2030B)*****:** This scenario was motivated by the existing but limited land use policies gathered from national, state and district level and downscaled for regional level. These policies are mostly related to forest conservation, change in agriculture practices, infrastructure development and those related to the issues of waste land. It promotes plantation of new species of trees which may not be indigenous in nature, and thus changes the biodiversity and wilderness of the region. Although forests are being conserved, they are changing in structure from dense to open type resulting in more human-wildlife conflicts. Agricultural policies concentrate on increasing tea and spice production by clearing land from forests. Also use in intensive agricultural practices using pesticides and fertilizers are promoted.

2) ***Land use change with climate change adaptation and conservation policies in play (LU-2030C):*** This policy scenario was designed with the intension of conserving the indigenous forests, reduce soil degradation, increase water yield and changes in agricultural practices like multiple cropping, organic farming, alternative source of energy etc. We also included physical and social infrastructure in areas which were not eco-sensitive in nature. We employed a recognised method of scenario development (Huber et al., 2014), using expert judgement with quantitative indicators recommended in the Land Use Model (Eastman, 2015).

For each transition, a mathematical sub-model was developed. Sub-models are based on the combination of user-selected explanatory variables, using regression and Maximum Likelihood method (Clark and Hosking, 1986; Geneletti, 2013). Finally, sub-models were generated including variable like built-up, roads, elevation that showed high association with different land use classes (Eastman, 2009). Next, the year of prediction of future land use change or transitions was set. Finally land use scenarios for 2030 were generated for two future scenarios.

6.2.2.2 Ecosystem modelling

Different ecosystem services were identified during field work (Table 6-1). However, only a few ecosystem services were further analysed for this study because of limited data availability. The selected ecosystem services were modelled across the two land-use scenarios described above as well as for 2014 land-use, which formed the basic temporal and spatial unit for comparison. Ecosystem services modelling were performed through GIS-based models on IDRISI (Eastman, 2015; Sharp, 2014). Outputs were presented at pixel level. An overview of the modelled eco system services like carbon sequestration, water yield, soil retention, timber production and food production are as follows.

Table 6-1: Potential ecosystem services identified in the study area and those analysed are in bold

Category	Sub-Category	Example
Provisioning	**Agriculture**	Tea, Cardamom, tomato, wheat and fruits
	Livestock	Sheep, Got, Poultry , Pigs
	Forest products	Pine wood, honey
	Fresh water	Agriculture and human use
Regulating	Air quality	Air purification
	Climate regulation	CO2 sequestration
	Habitat maintaining	Biodiversity and Natural protected areas
	Water regulation	Riparian vegetation, water in-filtration
	Erosion control	Terraces, deforestation
	Soil fertility	Water courses and riversides
Cultural	Spiritual value	Home to spiritual tribes
	Nature tourism	Hiking, mountain activities and home stay

Carbon sequestration

The carbon sequestration was based on the amount of carbon accumulated in aboveground biomass, belowground biomass, soil organic matter ,dead organic matter and forest harvest wood products (Houghton et al., 2012; Sharp, 2014). From the land use classification, each land-use type quantified carbon storage level. Changes in carbon storage were based upon the transition from one land-use type to another over a period of time. Data on carbon stored in different carbon pools and every land-use class were taken from IPCC Guidelines for National Greenhouse Gas Inventories (Eggleston et al., 2006). Integrating this data for the selected site and using the Carbon Storage Model in software IDRISI, results were obtained that showed the amount of carbon stored for current land use and future scenarios.

Soil conservation

Soil conservation has become a key concern in mountain regions. Change in climate patterns and unexpected high intensity rains has severe impacts on soil conditions which further effects agriculture production on slopes, water retaliation and landslide events. Therefore for this study soil conservation is one of the key factors affecting adaptation response to climate change. Soil conservation as an ecosystem service refers to the capacity of natural vegetation to keep soil in place. Soil conservation service was modelled by including erosion rate on the selected case study with the change of vegetation and non vegetation land. Erosion rates were predicted using the Universal Soil Loss Equation (Wischmeier and Smith, 1978) with the help of GIS tool (Eastman, 2015) that consider variables like land use, soil type, precipitation and DEM.

Timber production

Timber is an important product for the local people in the selected and a source of income to the local government. In this study timber production was considered as an ecosystem service provided by forests and was estimated by using the forest land use based on the work by Geneletti (Geneletti, 2013; Nelson et al., 2009). The timber production was analysed using data on harvest level and harvest cycle for the forest area. The data for selected case study were collected from local and district forest departments. The analysis was based upon timber productive capacity of the forest area (Haynes, 2003).

Food production

Food production is an important source of livelihood for the communities in the selected area.

The region is known for good quality of Darjeeling tea, spices, flowers, fruits and vegetables. In the last decade the region has been facing impact of climate change and human interventions on food production. The changes in food production in relation to changes in agricultural practices were assessed for current and future land use scenarios based on Huber et al. (2014) and Briner et al.(2012) . Recent production data were not available with the local government department. Therefore past production data and the extracted agricultural land use class for 2001 and 2014 was used to quantify food production ecosystem service.

Water yield

The provision of fresh water for human and agricultural use is a basic but essential ecosystem service. The people in the selected area have started facing water stresses during dry seasons as well as the monsoon season. For this study conservation of water at local level and watershed level has become a dire urgency for social and agriculture activities. Based upon the current land use class, soil depth, plant available water content, annual precipitation, water runoff at the watershed and sub watershed level water yield was used as input data to evaluate water yield for the current year and future land use scenarios. Water conservation policies in the district inspired the future scenario analysis. Working analysis methodology was based upon the work of Briner et al. (2012) and Eastman (2015).

6.2.2.3 Socio economic analysis

For this purpose expert interview and meeting were held with government and community based organisations to select a suitable study site. We used semi-structured interview, group discussion and detailed questionnaire surveys at household level to understand the socio-economic structure and concerns of climate change for different villages in the selected site. The survey was conducted during the month of April – May, 2014, by the Darjeeling based civil body named Anugyalaya Darjeeling Diocese Social Service Society. The survey covered six villages in Kalimpong Block I and II of Darjeeling districts (Table 6-2). A total of 969 people were covered living in 187 households in 6 target villages. Of the 969 people, 53% are males and 47% are females. 29.21% of the population constituted of children below the age of 18 years of which 146 are males and 135 females. Using the data we conducted descriptive analysis.

Table 6-2: Socio-demographic profile of the villages in the study area

Variables / Village		Gitkolbong	Passabong	Pakang	Mahajan Dara	Paila Line	Munshi Dhura
Population	Total Household	30	40	30	30	36	21
	Total population	147	180	171	185	162	116
	% Female	51.7	45.56	53.80	47.03	41.98	36.42
	% Male	48.3	54.44	46.20	52.97	58.02	35.19
Age (%)	< 16	25.1	32.22	26.32	33.51	30.25	18.52
	> 16	74.9	67.78	73.68	66.49	69.75	53.09
Social group (%)	General	10	0.00	3.33	0.00	22.22	4.76
	SC	0	0.00	0.00	0.00	0.00	9.52
	ST	30	37.00	26.67	40.00	36.11	61.90
	BC/OBC	20	3.00	70.00	60.00	41.67	23.81
Employment (%)	Primary Sector	73.3	62.00	93.33	93.33	97.22	76.19
	Secondary sector	20.7	29.00	3.33	6.67	2.78	4.76
	Tertiary Sector	6	9.00	3.33	0.00	0.00	19.05
Family Income (%)	< 40 K	46.6	23.00	26.67	10.00	97.22	28.57
	40 K - 60 K	26.6	10.00	50.00	80.00	0.00	66.67
	60 K - 80 K	6.6	6.00	16.67	10.00	0.00	4.76
	> 80 K	20	1.00	6.67	0.00	0.00	0.00
Food Security (%)	<3 Months	63.3	21.00	73.33	66.67	97.22	47.62
	3 Months	23.3	13.00	26.67	33.33	2.78	47.62
	6 Months	13.3	6.00	0.00	0.00	0.00	4.76
	9 Months	0	0.00	0.00	0.00	0.00	0.00
	>12 Months	0	0.00	0.00	0.00	0.00	0.00

Source: Primary survey conducted with the help of local organisation (Anugyalaya Darjeeling Diocese Social Service Society)

6.3 Results

6.3.1 Land use change analysis

The results of land use change analysis showed that major changes were occurring in the form of conversion of forest and agricultural land to waste land as well as increase in built-up area from 2001 to 2014. Increase of waste land was 14.80%, built up area by 7.35%. Increase of agriculture land use was 8.61 % of which are transitions area from forest and other land use classes (Figure 6-4). Changes of land use class forest and agriculture to waste land in likely to be the result of extreme climate impacts like landslide and loss of soil fertility because of extreme rain fall. Increase in agriculture land use seems to be the result of new forest villages and new agricultural activities. The rate of change in land use between 2001 and 2030 was used to forecast the land use pattern for 2030.

The results of land use scenarios from Land use modelling for 2030 are presented in figure (6-10). Two scenarios were developed for 2030 based on business as usual and conservation policies including ecosystem services approach. The 2030 scenario shows that, there was an increase in land fragmentation in business as usual scenario with significant loss of forest and agricultural land and increase in waste land. Whereas, in the conservation scenario for 2030, there is recovery and increase of forest land use from waste land. Also conservation scenario for 2030 shows less land fragmentation and improved agriculture pattern.

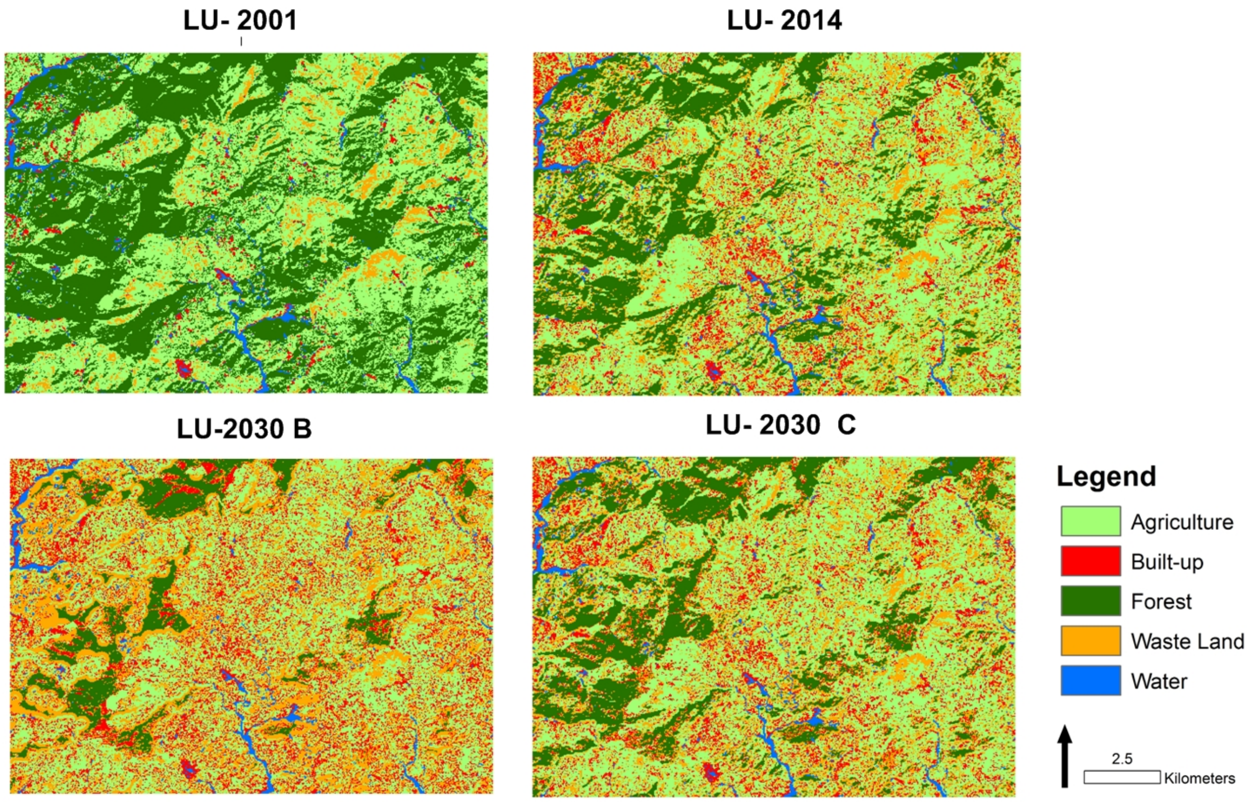

Figure 6-2: Land Use for 2001, 2014, 2030

6.3.2 Ecosystem services and scenario analysis

The results of ecosystem services provision for 2030 for two different scenarios are presented for following ecosystem services food production, timber harvest, carbon sequestration, soil retention and water yield (Table 6-1).

Food production

The overall food production for the study area under business as usual land use is likely to increase compared to land use under conservation scenario (19052 Kg for LU-2030 B and 17642 Kg for LU-2030 C) because of additional land being cultivated. However the food production measured as kg/ hectare will increase for land use under conservation (1850 Kg /Ha for LU-2030 B and 2900 Kg /Ha for LU-2030 C) due to changes in agriculture practices, increase in soil fertility and multiple crop practices (Figure 6-3).

Timber harvest

Observation from the land use analysis shows severe impacts of climate change on forest area in the form of landslide and conversion of forest areas to waste lands (Figure 6-4). The selected site also faces issues of water scarcity and soil retention capacity that has negative impacts on timber production. Timber production modelling shows decline in timber production under LU-2030 B scenario. There are two reasons for this decline; first is conversion of forest area to waste lands and second is an anthropogenic activity including agriculture activities. There is likely to be increase in timber production under LU-2030 conversion scenario because of decline in loss of forest area, conversion of waste land to forest area, plantation of more climate adaptive species of tree and stewardship by local communities towards conservation of biodiversity and forest area.

Carbon sequestration

Figure 6-5 reveals that results of carbon sequestration will differ significantly across both land use scenarios. Increase in agricultural production and decrease forest land cover for LU-2030 B scenario will result in lower carbon sequestration. There will be increase of built-up area that will result in energy use and increase in greenhouse gas emission. Whereas LU-2030 C scenario is likely to result in higher carbon sequestration because of substantial increase in forest area, availability of good quality timber per square area of forest, conversion of forest and agriculture land from waste land area.

Soil retention

Soil retention analysis shows decline in both the land use scenarios for 2030 (Figure 6-6). While, land use-2030 B show greater decline then Land Use-2030 C. Some of reasons for decline in soil retention will be changes in rain pattern, increase in high intensity rainy days, changes in topography, soil structure and agricultural practices in the study area.

Water Yield

Results of water yield analysis for the study area showed that majority of area will have decline in water yield for both the future scenarios compared to the current land use in 2014 (Figure 6-7). It was observed from the meteorological date for the study region that there will be a decline in annual rain for future with increased number of high intensity rainy days. Both of the scenarios will not be in favour of hydro power projects, but at the same time increase in number of landslide.

6.3.3 Socio-economic modelling

The socio-economic pattern and climate concerns of 6 villages in the study area showed that about 56% of total households belonged to local indigenous tribes and 37% from backward classes. Livelihood of 85% people depended on primary sectors like agriculture, tea production and forests and only 15 % of the total population were working in secondary or tertiary sector. The wages in this region are very less with about 50% household earning less the 650 USD per annum and about 40% households earning income ranging from 650 USD - 950 USD in a year. Household income has direct repercussions on food security for example about 70% of total household has food security for less than three months (Figure 6-8).

Households were asked to explain the major climate risks faced by them in the past years and its impacts. Most people confirmed that climate risks like increase in summer and winter temperatures, changes in rainfall pattern, erratic rain and shift in the seasons. They also identified second order risks like landslides, water scarcity and drought in pre and post monsoon seasons. These climate risks seemed to have direct impacts on livelihood and social structure of the selected villages like decrease in agriculture production, food security, pests in crops and health issues from changing climate variables (Figure 6-9).

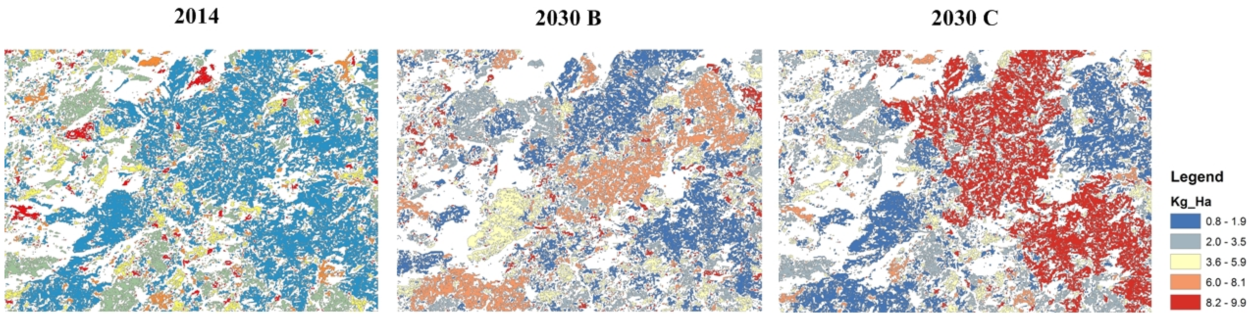

Figure 6-3: Results of ecosystem services for food production for current and future land use scenarios.

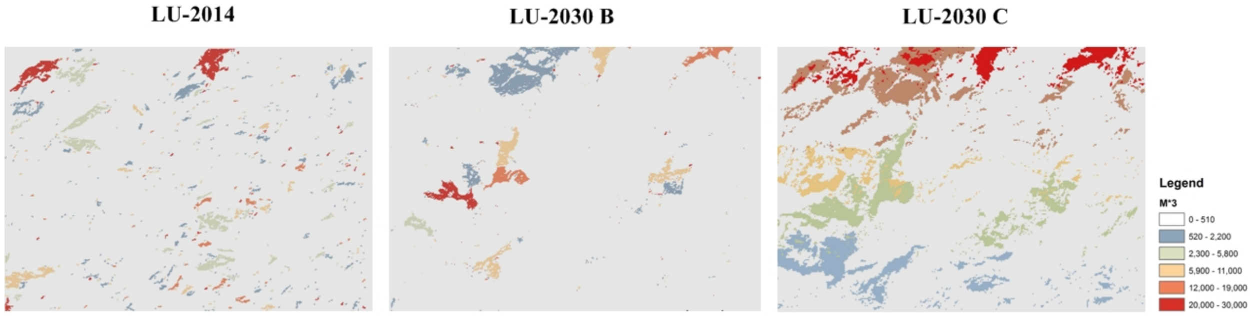

Figure 6-4: Results of ecosystem services for timber production for current and future land use scenarios.

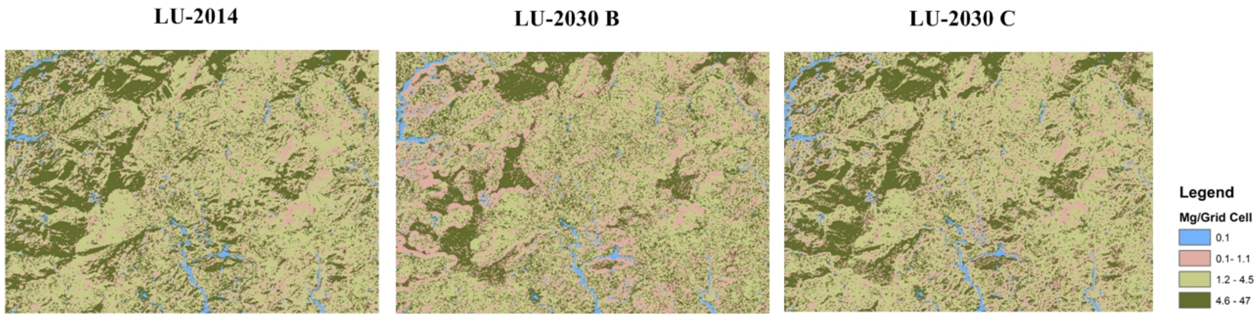

Figure 6-5: Results of ecosystem services for Carbon sequestration for current and future land use scenarios.

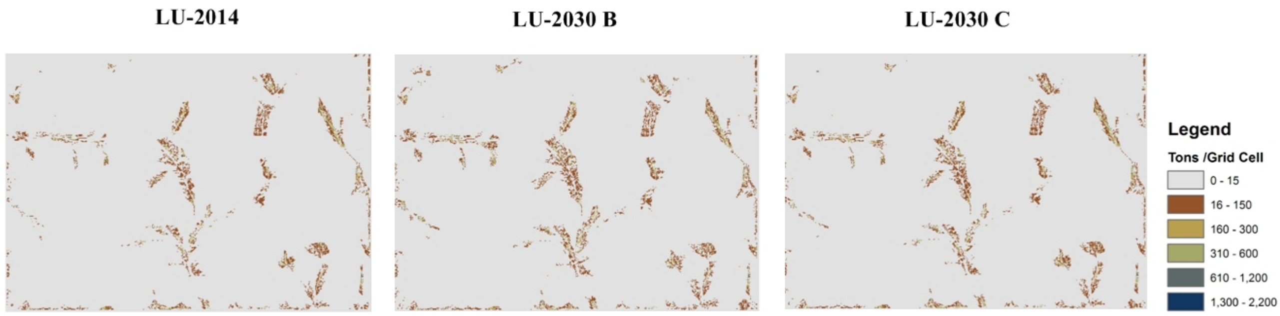

Figure 6-6: Results of ecosystem services for Soil retention for current and future land use scenarios.

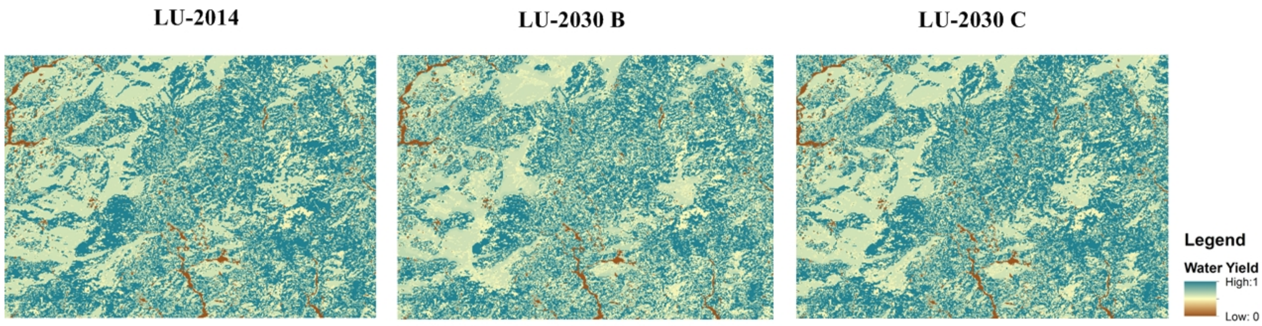

Figure 6-7: Results of ecosystem services for water yield for current and future land use scenarios.

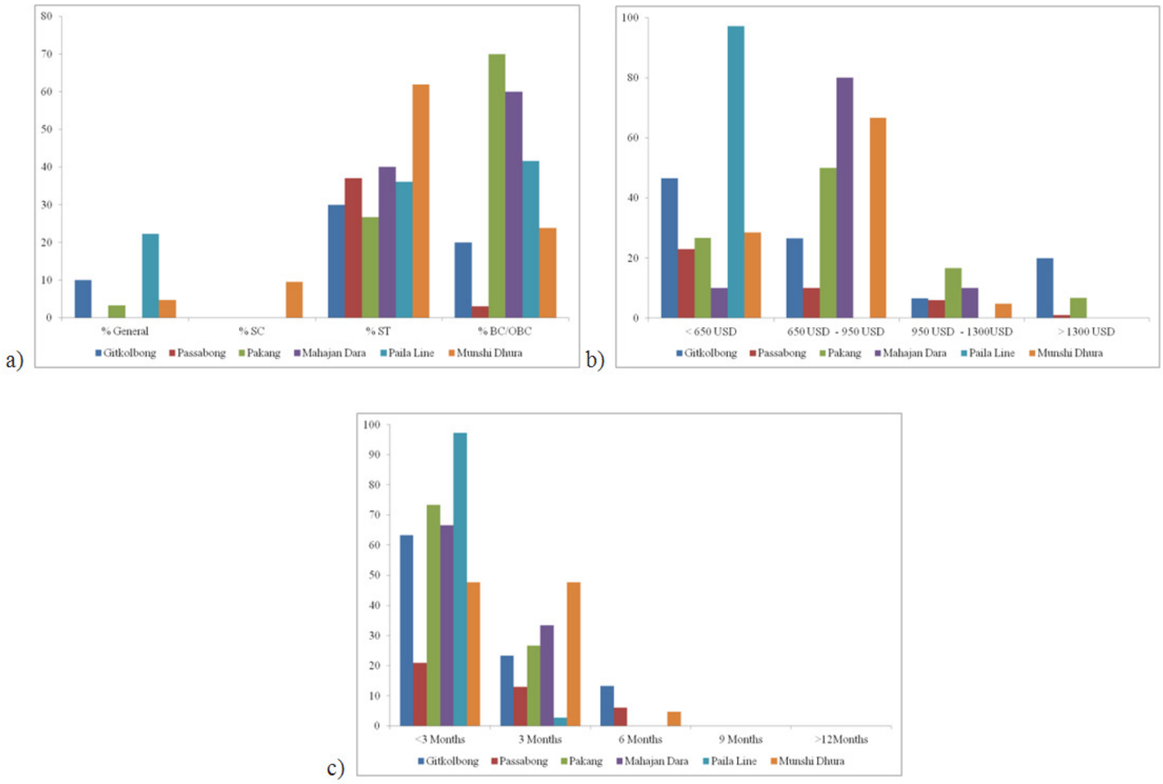

Figure 6-8: Descriptive comparison among villages a) Social group, b) Yearly household income and c) Food security.

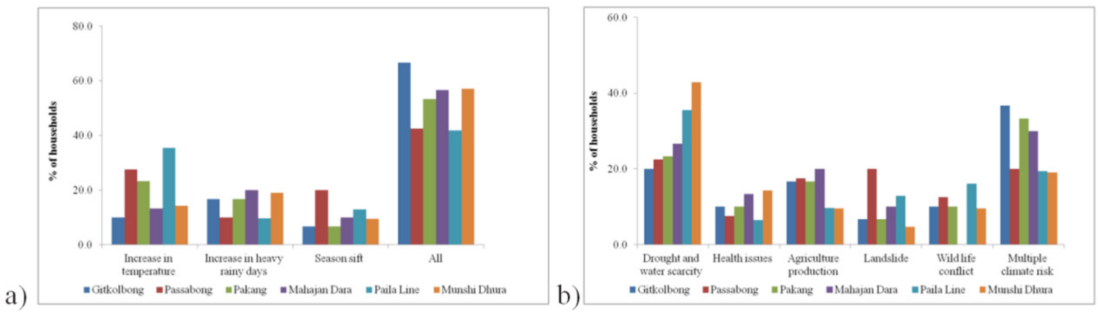

Figure 6-9: Climate change impacts according to informant from various villages, a) Direct impacts and b) Indirect impacts.

Informants were also asked to explain their social and economic asset like type of land and quantity of land owned by households, major cultivation and non-farm based activities. Descriptive analysis by villages is tabulated below (Table 6-3).

Table 6-3: Livelihood source and agriculture asset

Variables / Village		**Gitkolbon g**	**Passabon g**	**Pakan g**	**Maha jan Dara**	**Paila Line**	**Munshi Dhura**
Land Holding of the Family (%)	Farm land (>5 Acre)	0.0	2.5	0.0	3.3	0.0	4.8
	Farm Land (<5 Acre)	83.3	80.0	66.7	93.3	100.0	85.7
	Leased land	13.3	7.5	10.0	3.3	0.0	9.5
	Forest land	3.3	0.0	0.0	0.0	0.0	0.0
	Kitchen Garden	0.0	7.5	10.0	0.0	0.0	0.0
	Other	0.0	0.0	0.0	0.0	0.0	0.0
	N.A	0.0	2.5	13.3	0.0	0.0	0.0
Type of Land Owned by the family (%)	Irrigated Land	36.7	50.0	0.0	0.0	38.7	61.9
	Un Irrigated Land	63.3	50.0	0.0	0.0	58.1	28.6
	Waste Land	0.0	0.0	0.0	0.0	3.2	4.8
	Multiple Type Land	0.0	0.0	100.0	100.0	0.0	4.8
	N.A	0.0	0.0	0.0	0.0	0.0	0.0
Major Cultivation in Agricultural Land (%)	Grains	0.0	0.0	0.0	0.0	48.4	0.0
	Cereals	0.0	0.0	0.0	0.0	0.0	42.9
	Vegetables	40.0	50.0	0.0	3.3	22.6	19.0
	Fruits	0.0	0.0	0.0	0.0	0.0	38.1
	Flowers	3.3	2.5	0.0	0.0	0.0	0.0
	Medicinal/ Aromatic Plants	0.0	0.0	0.0	0.0	0.0	0.0
	Multiple Crop	6.7	35.0	103.3	96.7	29.0	0.0
	Other Cash crop	50.0	5.0	0.0	0.0	0.0	0.0
	N.A	0.0	7.5	0.0	0.0	0.0	0.0
Irrigation (%)	Perennial	36.7	50.0	96.7	86.7	0.0	100.0
	Seasonal	63.3	50.0	6.7	13.3	100.0	0.0
Non Farm based activities practiced (%)	Poultry	20.0	10.0	0.0	20.0	3.2	0.0
	Beekeeping	0.0	0.0	0.0	0.0	0.0	0.0
	Piggery	16.7	10.0	0.0	0.0	0.0	4.8
	Fishery	0.0	0.0	0.0	0.0	0.0	0.0
	Diary	63.3	75.0	0.0	0.0	16.1	4.8
	Other	0.0	0.0	0.0	0.0	0.0	4.8
	Multiple	0.0	0.0	103.3	76.7	67.7	81.0
	N.A	0.0	5.0	0.0	3.3	12.9	4.8
Type of seeds do you use in your agriculture land	Traditional Seeds	16.7	22.5	33.3	36.7	100.0	23.8
	Hybrid Seeds	83.3	77.5	70.0	63.3	0.0	76.2
	High Yield seeds	0.0	0.0	0.0	0.0	0.0	0.0

(%)	GM Seeds	0.0	0.0	0.0	0.0	0.0	0.0
Agriculture production (%)	Decrease	93.3	87.5	76.7	90.0	96.8	71.4
	Increase	0.0	5.0	3.3	0.0	0.0	9.5
	Normal	6.7	7.5	20.0	10.0	3.2	19.0

Source: Primary survey conducted with the help of local organisation (Anugyalaya DSSS, Darjeeling)

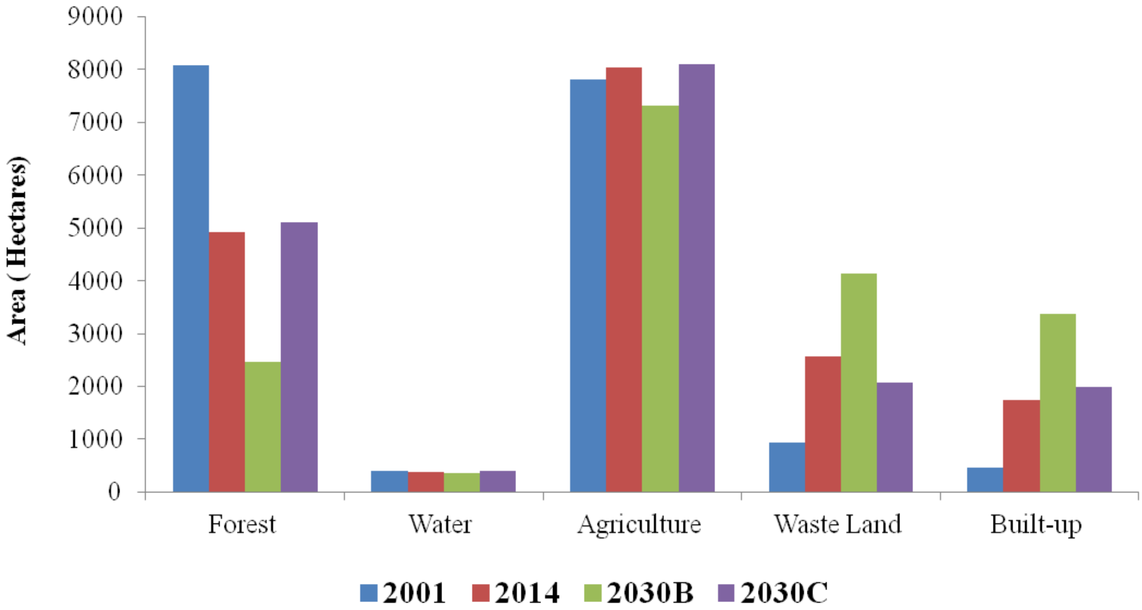

Figure 6-10: Land Use change comparison

Table 6-4: Summary of beneficiaries, indicators and policies for scenarios for different ecosystem services

Ecosystem service	Beneficiaries	Spatial indicators used to evaluate	Context specific policies in scenario for conservation (2030 C)
Food production	**Direct:** local subsistence farming for villagers **Indirect:** Tea, spices and other commercial crops for national and international market	• Land use cover • Agricultural production per hectare	• Multiple cropping practices • Promoting indigenous crops • Soil conservation, anti erosion and land slide reduction measures by plantations • Integrated management for pest and diseases
Timber harvest	**Direct:** Villagers and communities for timber, fodder, fuelwood and forest products like honey. **Indirect:** source of income for local government, international community for carbon sequestration	• Managed forest area • Proportion of harvest area • Biomass harvested per hectare • Harvest frequency • Maintenance and operation cost	• Monitoring invasive species and planting native species. • Reduce open forest, improve quality of medium forest and protect dense forests. • Prevent forest

		• Market value of harvested wood	fragmentation • Empower communities to protect biodiversity and forest • Reclaim waste land into forests
Carbon sequestration	**Direct:** Local, state and international community's by reducing GHG **Indirect:** Impacting microclimate of the region	• Current and future land use • Current and future storage carbon • Biomass conversion expansion factors for different land use classes • Carbon density and harvest frequency	• Conserve indigenous forest species • Planned harvesting of forest and yearly cycle monitoring • Changing dependence on forest fuel • Changing patterns of energy use
Soil retention	**Direct:** Villagers and agricultural communities that depend on the soil for production. Also reduce flooding and landslide hazards for people living downstream **Indirect**: Improve soil quality, food production, water purification, water availability.	• Watershed area • Land use classes • DEM • Rainfall erosivity • Soil erodibility • Sediment threshold • Soil type and depth	• Increase plantation and soil binding species • Plan agriculture of root vegetables and their harvest • Planning of proper drainage patterns • Control mining activities that effect top soil
Water yield	**Direct:** Villagers and communities for drinking water, irrigation and hydropower **Indirect:** local and state economics and infrastructure in the form of water and power	• Watershed area • Land cover • Annual precipitation • Evapotranspiration • Plant available water content data	• Local water storage practices and rain water harvesting • Plantations to increase water retention by soil • Water management and distribution planning

6.4 Discussion

The main aim of this study was to identify land use practices in the study area and alternative policy practices that will ensure safeguarding key ecosystem services that are subject to climate and land use changes. According to Cowling et al. (2008), ecosystem services based policies can be an effective model for good governance and resilient socio economic system when implemented in three stages: assessment, planning and management. This study covers the first two stages, wherein we assess how specific ecosystem services are affected by different scenarios of policies with regard to mountain communities. This type of studies will help in comparing the feedback of current policy scenario with alternative scenarios to help make informed decision by governing bodies.

The results of the study can be summarised in three points. First, the socio-ecological survey was a necessity in this analysis to understand the beneficiaries of the ecosystem services of the region and the perception of the people on how they were being affected by present land use practices and climate change. It is worrying that without any knowledge about climate change as a scientific factor, people still perceive noticeable changes in the climatic conditions of the region and significant decrease in crop patterns due to climatic variables. The socio ecological study also shows how changes in ecosystem services of a region not only affect the direct beneficiaries like the villagers and communities of the region but also indirect beneficiaries namely stewards and intermediaries. Stewards are people whose actions result in modification of the ecosystem services such as government and local planning bodies, and intermediaries are those who mange interaction among beneficiaries, stewards and ecosystem services (Willemen et al., 2013). In these remote areas of the Himalayas, the role of government bodies and stewards is often minimal. It is then that intermediaries such as civil societies and self-help groups that can initiate ecosystem based conservation practices among the locals to improve socio-economic condition and adaptive capacity.

Secondly, rapid land use change is evident even at this small scale of mountain ecosystem and shows dependence on the rate of climate change and magnitude of socio economic development. The first factor that is affecting the changes in land use is increase in population of the region. As a result, there is extension of agricultural land into forests and restricted landscapes, to cope with local and global demand. The second factor for land use change is increase in wastelands owing to frequently occurring lands slides. Landslides are increasing in the region because of anthropogenic causes such as deforestation, illegal mining, unplanned transportation and big dam constructions (Mukherjee, 2013).

Thirdly, in order to conserve the region as well as cater to the growing population, it is necessary that resources are used in a planned and sustainable manner. The results from the scenario analysis of ecosystem services of the region shows that given the nature of the existing regional plans that concentrates on economic and social issues, the ecological conservation of the region will be completely neglected. Individuals or groups that are interested in ecological conservation are often not embedded into the planning and implementation mechanism (Ingold et al., 2010) and therefore are not capable of executing change. Therefore traditional and informal processes are likely to be most beneficial in the preservation of ecosystem services with a minor support from governing bodies in the form of broad ecosystem based planning mechanisms. An example of protecting water yield as an ecosystem service with traditional methods is mentioned in Mukherjee (2013), where he reports how people in the Himalayas have been for years traditionally practicing rain water harvesting, constructing channels for water distribution, regulating water distribution and drawing fresh water as community practices. Their source of fresh water are the innumerable natural springs in the watersheds (called dhara, pandhera etc) which are carried to homes by using natural pipes made by bamboo poles. Another example of loss of ecosystem services due to changes in land use patterns is evident by the decrease in soil retention and desertification due to over cultivation, excessive grazing, deforestation and flawed irrigation practices. It is estimated that in the Darjeeling district of the Himalayas, soil erosion is 10 times more than the natural amount of soil formation (Mukherjee, 2008). Local agricultural research organization such as Uttar Banga Krishi Viswavidyalaya has now influenced farmers to start practicing conservation tillage by leaving a portion of the crop residue to increase soil retention and water capacity.

Therefore, climate change and land use change will have significant impacts on the local economy and social structure of the mountain communities. Increasing erratic rain fall events with high slope terrain will increase the frequency of landslide, decline soil retention and impact on agricultural production. Engineering approaches like building concrete protection walls is expensive and a logistical hassle for economical poor regions and over natural barriers. Ecosystem based climate responses can thus play an important role to mitigate global and local climate concern with least negative repercussions (Millennium Ecosystem Assessment, 2005; Barbier et al., 2008; Everard et al., 2010; Gedan et al., 2010; Shepard et al., 2011; Pinsky et al., 2013). Although ecosystem based adaptation responses to climate change is underexplored with the spatial planning policies by decision makers, it can be taken up informally by the communities with only a small guidance from the local government.

Chapter 7

7 Synthesis

The main aim of this study was to contribute towards understanding climate change risks and perception in spatial planning policies at local level. By investigating spatial planning policies, an assessment framework and decision support system was built that aimed to improve current spatial planning practices and planning tools intended at building resilient living spaces. In this chapter, I try to summarise the strengths and weaknesses of the key objectives, methods and findings described in the earlier chapters. At the same time, I try to understand the theoretical and policy implication of this study.

7.1 Objective 1

(Chapters 1 and 2): To develop and test an assessment framework to track integration of climate change issues into spatial planning.

7.1.1 Main findings

The objective of this study was the first step towards identifying the key gaps and potential areas of focus, to integrate climate change issues at urban/regional level in India. The literature review on the kay gaps was done in chapter 1. Spatial plans across various cities in India were examined. The skeleton of the review framework was developed based on Moser and Loers (2008) work on "Managing climate risks". The results of this study show that the role of spatial plans to integrate climate change issues at the city level in India are still limited. The detailed study of the planning practices in India brought to light the gaps in the system and identified that local governments and development organizations require technical skills, financial capabilities and planning instruments to analyse the impacts of changing climate variability and act upon them. Local government failed to consider climate change as an issue while preparing spatial policies and to take advantage of international and national climate change policies and knowledge base.

Spatial policy making practices in India have considerable differences in different regions and spatial scales. Consequently, there is a need for a national and at the same time region specific integrated frameworks to include climate change that can guide policy makers. Climate change issues in the spatial planning process requires significant changes in the way spatial policies are prepared at various scales in India. More powers to local governments to take independent decisions and action concerning to climate change issues are required for development of the region or local level. There is a National Climate Change Action Plan and a few state level plans, which cover broad schemes and does not reach the level of detail required for urban and regional implementation. It can be hoped that states will be able to better manage their funding for policy actions, with the current government announcing in 2015, that 10% more central government funds will be released to the state for region specific development. Effective climate change policies must take into account climate change related beliefs, attitudes and behaviour of the native people, which play a vital role in the success or failure of these strategies through their decisions as citizens, consumers and as a community. Awareness of climate change issues and its impacts on socioeconomic and biophysical aspects should be spread across all the stakeholders. Media, Non-governmental organizations (NGOs) and environmental agencies can play an important role to make people aware about various climate change issues and its impacts.

7.1.2 Strength and weakness

7.1.2.1 Strength in the method

This study is unique in being one of the few studies that attempts to scientifically and systematically assess the integration of climate change policies at local level especially in urban areas in India. Several authors have addressed the question of how climate change can be integrated into the various policy agendas by proposing different frameworks (Brooks et al., 2011; Lim et al., 2005; UNISDR, 2012; Urwin and Jordan, 2008). However most of these assessment frameworks are outcome or sector oriented (Tang et al., 2010), and are used to understand the key gaps and issues related to the climate concerns in policies (Preston et al., 2011; Urwin and Jordan, 2008; Wilson, 2006). While the review framework that was developed in this study focuses on planning processes and potential outcome of spatial plans in future. The review framework has potential to assess key components like awareness among policy makers of the key drivers of climate change and its impacts at the local level (Baker et al., 2012; Lindseth, 2004). In addition, the framework was able to review the key gaps in the extent to which the spatial plan shows a capacity to analyse, quantify and synthesize the available information on climate change in a useful form to support planning decisions (Baumert et al., 2005; Brooks et al., 2011). Developed review framework is robust policy analysis tool and can be applied to evaluate policies at local spatial scales in other geographical areas keeping in mind the spatial and contextual subjectivity.

7.1.2.2 Weakness

The key weakness of this undertaking this objective was not including adequate perception of policy makers and different stakeholders involved in spatial planning policies. Perception and knowledge gained from policy maker could help to understand their limitation in terms of awareness and key concerns for integration of climate change into spatial plans in terms of economics, facilities and political agendas.

7.1.3 Future research

Further research on the topic in required and could focus on the following issues:

- How climate policies at higher spatial scales can be integrated into local policies, streamlining response actions on ground and implementation structure.
- The current study was only limited to spatial plan documents and it will be interesting to see how sectoral policies benefit spatial plans on climate change issues and its impact on the ground.
- One of the key limitations of this study was evaluating the effectiveness of spatial plans on the ground. Future study will use one of the key sectors from the spatial plans (example land use, ecosystem, resource management, physical development, etc.) to further identify the integration of climate changes issues and action taken by local government to reduce the vulnerability.

7.2 Objective 2

Chapter 3, 4 and 5: To identify hot spots of climate change at urban/regional levels by applying spatial vulnerability assessment tools.

7.2.1 Main findings

In fulfilling Objective 2 an attempt was made to sort the growing concern among scientists as well as from policy makers over the large number of assessment framework for climate change and its usability at local level. Each assessment method has its strength and weakness to guide policy makers to deconstruct the complexity of climate change issues and to develop response action to climate change. However majority of them are useful at coarse scale and lacks the standardized working methods (Preston et al., 2011). At the same time these assessment framework lacks the ability to demonstrate clarity and consistency in the selection of indicators, aggregation of indicators, and comparison across different indicators (Eriksen and Kelly, 2007; Rannow et al., 2010). In chapter 4 and 5 an attempt is made to understand the weakness of available assessment methods and build working methodology and its application for local spatial scale. An effort is made to understand the practical challenges in applying and replicating available vulnerability assessment methods at local spatial scales.

According to Preston, et al.(2011) to operationalise vulnerability assessment, it is important to understand the spatial context of the assessment. Majority of studies highlight climate concern from biophysical perspective and from developed nations, especially on coastal regions where impacts due to sea level rise and natural disasters are more apparent (Castán Broto and Bulkeley, 2013; Hunt and Watkiss, 2011). The framework used in this chapter attempts to understand the climate change concern from non-coastal regions impacts on socio-economic and ecological aspects of the local area (Daron et al., 2014; Engle, 2011; Forman, 2014).

7.2.2 Strengths and weaknesses

7.2.2.1 Strengths in method

The proposed vulnerability assessment framework for climate change was among the first attempts to adopt and integrate different aspects of spatial planning for local level. For example selections of indicators accounted for the key issues in spatial plans for the selected case study. The results of the vulnerability assessment show potential to support decision within the spatial planning preview to integrate climate concern into current and future policies. The overall results of the vulnerability assessment helps to understand the pattern and magnitude of climate change impacts as well as priorities of action spatially and by sector. The comparative analysis among indicators helps to make trade-off decisions and small interventions rather than a single dominant intervention. Presents vulnerability assessment framework can be operational at any local level that can help to prioritize response action either independently or in the spatial planning process.

This study also shows how simple open source technological tools can help policy maker at local level to develop decision support system to generate knowledge bases for developing response action.

7.2.2.2 Weakness

The key weakness in this chapter was not including the projection of exposure component of vulnerability assessment for the selected case study and limitation of critical data and detailed information required by the vulnerability assessment framework. A large number of urban regions in developing countries do not maintain historical records on a different aspect of the urban system and climate variables (Laukkonen et al., 2009). For the selected case study available databases were unstructured and sometimes irrelevant. It is also difficult to assess the quality and source of databases because of the presence of multiple organizations in a region. The other limitations of the assessment framework lies in the subjectivity linked to the selection of indicators, standardization and giving weights. This concern could be resolve by understanding the spatial planning and general policy framework and integrating knowledge of key stakeholder during the spatial plan preparation.

7.3 Objective 3

Chapter 6: To apply eco-system-based adaption responses to climate change in an urban region and identifying barriers.

7.3.1 Main findings

Under objective three, we tried to understand the ecosystem based adaptation response at local level through a case study in the Eastern Himalayan district of Darjeeling. Social and economic structure of this community is dependent on natural resources and ecosystem services provided by the natural resources. In the past few years, the region has been experiencing shift in climate variables that have multiple impacts that directly and indirectly affect the socio-ecological fabric of the mountain region. Lack of efficient policies intervention by local government made local mountain communities in this region to experiment and adapt to indigenous ecosystem approaches to reduce climate change impacts. In this chapter, we try to understand the effect of ecosystem based adaption policies and undertake a scenario analysis to evaluate its effectiveness. Perceptions of local communities, and existing policies were analysed to develop future land use scenarios.

7.3.2 Strength and weakness

7.3.2.1 Strength

Scenario analysis of ecosystem services based policies is an effective way to spatially visualise the effectiveness of different policies. It shows that there is need for integrating ecosystem services with forestry and biodiversity conservation policies or creating effective market incentives for sustainable land use practices.

7.3.2.2 Weakness

Lack of sectoral policies and data for current years has an effect on future scenarios development. In addition only a bundle of ecosystem service was analysed which may not give a holistic picture for an integrated planning process.

7.3.3 Future research

This study was developed on two future scenarios; further studies should focus on developing more scenarios and quantifying the effectiveness of each scenario for comparison and informed decision-making. Further study could also focus on benefits and drawback of ecosystem based and engineering based solution to climate change at different spatial scale and landscape.

7.4 Policy implication

In this section, we discuss the policies that should be considered to strengthen planning and decision making at local level to integrate climate change based on our analysis. Policy makers at the local spatial scale need to address both short and long-term vision of development and its interrelation to be able to integrate climate change responses into policies. Climate change adaptation for short terms may fulfil objective for current climate scenarios but may impose externalities in future (Adger et al., 2005b). So policy makers and local development organization need to carefully narrate climate resilient scenarios of socio-economic, ecological, physical development and land-use change along with resource demands (Tompkins and Adger, 2005).

The study indicates that policy preparation at local level in various cities in India still follows a top-down process. Various studies on climate change literature suggests that governments at top level have greater potential and power to develop plans to deal with climate changes issues (Hallegatte et al., 2011; Neil Adger et al., 2005; Stern, 2006a). In India new initiative have been started at national and state levels but once these plans and policies trickle down to regional or city levels, the climate change issues are absent. Despite having support from national and state governments, the impacts of mitigation and adaption response cannot be seen at local plans and its get devaluated with other development issues. Results of awareness and analysis components also show that there were many limitations and deficiencies in plans, resulting from spatial scale issues, inappropriate skills to see the environmental issues, financial resources, multiplicity of the organizations, political interferences, ignorance and degree of trade-offs with other issues.

Developing future scenarios for local spatial scales requires information from every stakeholder to include the perspectives each of them (Few et al., 2006). Sometimes this process is time consuming and beyond formal governmental structures but is crucial for ensuring knowledge, awareness, innovation and support and easy implementation of plans on ground (Tompkins and Adger, 2005).

7.5 Required reforms in organizational and planning practices

Learning from experience of national and international institutions, it appears that there is need to change the planning practices. There is a need for rapid institutional and social learning which should contribute eventually to effective adaptation that reduces vulnerability (Adger et al., 2007; Baker et al., 2012b; Hjerpe and Glaas, 2012). Considering climate change issues in the planning process requires significant changes in the way spatial policies are prepared at various scales. It involves cascading decision across different scale and stakeholder. Also to understand the climate change issues requires close collaboration of climate scientists, sectoral practitioners, spatial planners, administrator, politician and other stakeholders (Campbell, 2006). It also requires changes in organizational structure of authority or organization; which is also one of the limitations that emerge from the study (Adger et al., 2007).

Local development authorities and executive authorities in various cities in India are engaged in a broad range of activities such as implementing building standards, collection of garbage, community development, economic growth, and natural resource management (Pini et al., 2007). Meanwhile state governments devolve an increasing number of responsibilities to local governments. This poses challenges for the local governments because of lack of enough revenue to run its functions efficiently and start new ventures (Ivey et al., 2004; Pini et al., 2007). They are reluctant to take on additional responsibilities (River, 2006). This results in national, state and local government to hire private organization under public private partnership to develop city development plan for the major cities in India. Despite this, private organizations are unable to consider climate change issue in to spatial plans. Surprisingly the barriers identified in this study, such as lack of technical skills, knowledge base, and resources are almost same as it is identified in relation to other issues like urban poor, slums, physical development and natural resource management by local governments (Keen et al., 1994).

In terms of policy reforms, green infrastructure is particularly important for small- and medium-sized urban centres or regions. Decision to consider mitigation and adaptation solutions in the form of green infrastructure are cost effective and climate-sensitive than engineering based physical infrastructure.

In order to achieve more effective policies, local governments need to expand the scope, accountability and effectiveness of participating NGOs, community and grassroots self help groups, academicians, the private sector and leaders. This will help to develop innovative options, as well as both scientific and locally relevant knowledge.

7.6 Conclusion

This thesis integrates a variety of concepts in climate change policies at urban and regional levels with an aim to plan for a climate resilient future. With sustainable development as the ultimate aim, it assesses current policies that are effective or mute in considering mitigation as a way to reduce climate change impacts rather than increase them. It considers the effectiveness of adaptation strategies to cope with situations where impacts of climate change cannot be avoided. And it considers different response actions in the form of policies and their capacity to ease the threats of climate change that threatens the stability of India. Results of this study reveal that there is broad understanding and interplay among national, state levels policies for climate change issues. However, these policies and response actions are not sufficient to avoid impacts of climate change that are deteriorating conditions at an alarming rate. There is a strong likelihood that majority of socio-economic hubs, natural resource regions and concerned communities in India will fall behind to integrate climate change response action towards resource shortage, direct and indirect climate impacts and socio economic stability. One response that will emerge will be quick geo-engineering fixes that will further exasperate the problem (Denton, 2014). In order to avoid such a situation, research such as this is extremely important, that strengthens the knowledge base to essentially act as a foundation over which climate change policies can be built for sustainable development of the country.

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Appendix 1. The scoring framework to assess the information within the criteria

Criteria	Score 1	Score 2
Concept of climate change or global warming	The broad concept of climate change or global warming has been stated and minor discussion of specific concept with some consideration of policy response.	There is clear vision about the concept of climate change and how it has an impact at various spatial scales and locality. Goals and objectives to be recognized and response priorities have been identified with explanation or justification.
Prediction of the impacts of climate change on the biophysical/social/economic context of the planning area	Basic evidence or acknowledgment of climate change impacts and climate change issues on biophysical /social /economic context of the planning area.	Climate change vulnerability at various scale and sector wise has been assessed.
Long term goals and targets for changing climate variability and its impacts	The broad climate change strategies have been stated, as well as some discussion of specific objectives, with some consideration of adaptation priorities on various climate related issues but has not been explained on how to implement it on ground.	There is a clear vision about the goals of the action response for climate change and how it supports wider goals or targets in spatial plan, objectives that allow progress towards the goals to be recognized and adaptation priorities have been identified with some explanation or justification.
Guidance and standards for the implementation of adaptation and mitigation measures in planning area	A range of policies and action plans to acknowledged the need of guidelines and standards on issues like GHG emission , energy , water etc.	Spatial plan included guidelines and standards for climate changes concerns like energy, water, pollution and environmental protection etc.
Base year assessment of GHG emission	Spatial plan provides base year assessment of GHG emission at various spatial scales and location.	GHG emission have been assessed in term of historical trends, current variability and projected future changes
Categorization of GHG emission type and source	The relevant source if GHG emission have been identified or are planned to be assessed	The relevant source if GHG emissions have been assessed in term of historical trend and current variability.
Future emission trends forecast	Based upon historical and current GHG emission, development policy goal for future emission have been	Based upon historical and current GHG emission, development policy goals for future emission are forecasted and have

	predicted or are planned to be assessed.	been predicted.
GHG emission scenario development	GHG emission scenario is identified or are planned to be developed in the spatial plan development process.	Goals for GHG emission scenarios are made during the spatial plan development process
Assessment of the physical development	The current nature or status of physical asset and resource stocks that are sensitive to climate risks or integral in their management have been acknowledged, or are planned to be assessed.	The current nature or status of physical asset and resource stocks as well as associated institutions, organizations and businesses responsible for designing, delivering and implementing adaptation measures, which are sensitive to climate risks or integral in their management have been assessed.
Assessment of the transportation system in relation to climate change issues	The current nature or status of traffic and transportation system and infrastructure that are sensitive to climate risks or integral in their management have been acknowledged, or are planned to be assessed.	The current nature or status of traffic and transportation system and infrastructure and associated institutions, organizations and businesses responsible for designing, delivering and implementing action response under transport policies, which are sensitive to climate risks or integral in their management have been assessed.
Assessment of water and sanitation situation in relation to climate condition issues	The current nature or status of water and sanitation system and infrastructure which are sensitive to climate risks or integral in their management have been acknowledged, or are planned to be assessed.	The current nature or status of water and sanitation system and infrastructure and associated institutions, organizations and businesses responsible for designing, delivering and implementing action response under water and sanitation, which are sensitive to climate risks or integral in their management have been assessed.
Assessment of energy demand and supply	The current nature of demand and supply of energy in various form, which is sensitive to climate risks or integral in their management have been acknowledged, or are planned to be assessed.	The current nature demand and supply of energy in various form and associated institutions, organizations and businesses responsible for designing, delivering and implementing action response under clean energy, which are sensitive to climate risks or integral in their management, have been assessed.
Assessment of land use change in relation to climate change	The current nature or status of land use which are sensitive to climate risks or integral in their management	The current nature or statuses of land use which are sensitive to climate risks or integral in their management have been

	have been acknowledged, or are planned to be assessed.	assessed.
Assessment of the consequence of the changing climate on natural and protected area	The current nature or status of natural resource stocks and environmental services which are sensitive to climate risks or integral in their management have been acknowledged, or are planned to be assessed.	The existing nature or status of natural resource stocks and environmental services and associated institutions, organizations and businesses responsible for designing, delivering and implementing adaptation measures on natural and protected area, which are sensitive to climate risks or integral in their management have been assessed.
Assessment of the consequence of the changing climate poverty distribution pattern	The current statuses of poverty, deprivation distribution and spatial location which are sensitive to climate risks or integral in their management have been acknowledged, or are planned to be assessed.	The existing nature or status of poverty , deprivation distribution , resource with the poor community and associated with those institutions, organizations and businesses responsible for designing, delivering and implementing adaptation measures for poverty , which are sensitive to climate risks or integral in their management have been assessed.
Displacement and forced migration cause of changing climate variables	Existing nature of forced migration and experience of individuals of various impacts of climate change and forced to move to other region have been acknowledged or are planned to be assessed.	Existing nature of forced migration and experience of individuals of various impacts of climate change and forced to move to other region and associated institutions, organizations and businesses responsible for designing, delivering and implementing adaptation measures which are sensitive to climate risks or integral in their management have been assessed.
Assessment of the employment and livelihood structure	Existing human skills, nature of employment and source of livelihood and experience of individuals responsible for adaptation planning and implementation have been acknowledged, or are planned to be assessed.	The existing human skills, source of livelihood and experience of individuals responsible for adaptation planning and implementation have been assessed.
Assessment of the sectoral economy of the planning area	Existing stocks, flows of financial resources and economic region and obligations associated with those institutions, organizations and businesses responsible for designing, delivering and implementing	Existing stocks ,flows of financial resources and economic region, associated with those institutions, organizations and businesses responsible for designing, delivering and implementing adaptation measures,

	adaptation measures have been acknowledged, or are planned to be assessed.	which are sensitive to climate risks or which can be used to manage climate risks have been assessed.
Cost estimation of the physical asset disaster	The cost estimation climate sensitive physical assets or damaged during the disaster have been identified or are planned to assessed.	Method of cost estimation of climate sensitive physical assets or damaged physical assets has been assessed in terms of historical trends, current variability and projected future changes.
Cost estimation for GHG emission reduction	The relevant cost estimation for GHG emission reduction has been identified, or are planned to be assessed.	Method of cost estimation for GHG emission has been assessed in terms of historical trends, current variability and projected future changes.
Assessment of the organization and political support to have the capacity to act on climate change issues	Addressed the issues by local body and political support but not explained further.	Identified various stakeholder and respective roles and there involvements while preparing various policies.
Engagement of relevant stakeholders	There has been interaction with stakeholders during the production of the adaptation strategy, or will be during the adaptation process.	Stakeholder engagement is central to the adaptation process.
Definition of roles and responsibilities	Roles and responsibilities for different adaptation measures have been acknowledged or will be considered.	Roles and responsibilities for different adaptation measures have been assigned.
Exploitation of synergies with other climate change policies	Synergies with other policies and programs have been or will be recognized.	Integration with other policies and programs has been or will be achieved.
Disaster-resistant land use and building code	Existing spatial plan and development institution are planning to encourage disaster-resistant land use and building code.	Existing spatial plan and development institution have adapted disaster-resistant land use and building code.
Conservation of parks, forest, natural and protected area	Existing spatial plan and development institution are planning to encourage and integrating conservation of eco-region within the space which is sensitive to climate change.	Existing spatial plan and development institution are adapting and integrating conservation of eco-region areas within the space which is sensitive to climate change.
Infill development and reuse of remediated brown field sites	Existing spatial plan and development institution are planning	Existing spatial plan and various development institutions are adapting

	to encourage Infill development and reuse of remediated brown field sites.	and using brown field sites for new development.
Green building and green infrastructure standards	Existing spatial plan and various development institutions are planning to encourage policies or guidelines to integrate green building and green infrastructure.	Existing spatial plan and development institution are adapting policies and guidelines to integrate green building and green infrastructure.
Low-impact design for impervious surface	Existing spatial plan and development institution are planning to encourage building design and standards for low impact design.	Existing spatial plan and various institutions have adapted building design and standards for low impact design.
Pedestrian and bicycle-friendly, transit-oriented community design	A range of policies and action plans to include and encourage public transport and pedestrian facilities to the region.	A range of policies and action plans to include like public transport and pedestrian facilities to the region have been implemented.
Multimodal transportation strategies	A current status of transport system and range of policies like multimode transport system and transport oriented development have been planned to be considered or identified.	A current status of transport system and range of policies like multimode transport system and transport oriented development have been developed or planned to developed.
Climate proofing of transport infrastructure	Policies like climate proofing or sensitivity to transport infrastructure have been acknowledged or are planned to be assessed.	Policies like climate proofing or sensitivity to transport infrastructure have been assessed.
Renewable energy and solar energy	Alternative options to conventional energy like renewal or solar energy are planned to be considered or to identify in the spatial plan.	Alternative options to conventional energy like renewal or solar energy have been planned or identified in the spatial plan.
Energy efficiency and energy stars	A range of policies and technological instruments are planned, considered or acknowledged to increase the energy efficiency.	A range of policies and technological instruments are considered and acknowledged to increase the energy efficiency.
Waste management and GHG mitigation technologies	Existing infrastructure for waste management and GHG mitigation technologies which are sensitive to climate risks or integral in their management have been acknowledged or are planned to be assessed.	Existing infrastructure for waste management and GHG mitigation technologies which are sensitive to climate risks or integral in their management have been assessed.

Waste water control and treatment	Existing infrastructures for water control and treatment which are sensitive to climate risks or integral in their management have been acknowledged or have been planned to be assessed.	Existing infrastructure for water control and treatment which are sensitive to climate risks or integral in their management have been assessed.
Policies to provide health facilities , insurance , food security and education	The current nature or status of health policies, health facilities and social security which are sensitive to climate risk or integral in their management have been acknowledged or are planned to be assessed.	The current nature or statuses of health policies, health facilities and social security which are sensitive to climate risk or integral in their management have been assessed.
Financial / budget commitment	Existing stocks and flows of financial resources and associated institutions, organizations and businesses responsible for designing, delivering and implementing spatial plan and climate change response have been acknowledged, or are planned to be assessed.	Existing stocks and flows of financial resources and associated institutions, organizations and businesses responsible for designing, delivering and implementing spatial plan and climate change response, which are sensitive to climate risks or which can be used to manage climate risks have been assessed.
Identify role and responsibility among sectors and stakeholders	Roles and responsibilities among various sectors and stakeholders for spatial plans have been acknowledged or will be considered.	Roles and responsibilities among various sectors and stakeholders for spatial plans have been assigned.
Public awareness and education about the climate change issues	The climate change issues, impacts and responses under spatial plan have been or will be communicated clearly to the concerned community.	A communication strategy has been established, placing the strategy within broader dissemination and outreach activities (e.g. websites, workshops).

Appendix 2. Spatial plans from various cities in India

Sate /Union territory	Name of the City /State	Type of the Plan	Spatial scale	Language	Organizational structure
Jammu and Kashmir	Jammu	Master Plan	City level	English	Development Authority
	Shri Nagar	City Development Plan	City level	English	Development Authority
	Shri Nagar	Master Plan	City level	English	Private organization
Punjab	Amritsar	Master Plan	City level	English	Private organization
	Amritsar	City Development Plan	City level	English	Private organization
	Ludhiana	Master Plan	City level	English	Private organization
Chandigarh	Chandigarh	City Development Plan	City level	English	Private organization
Uttarakhand	Dehradun	Master Plan	City level	Hindi	Development Authority
	Dehradun	City Development Plan	City level	English	Private organization
	Haridwar	City Development Plan	City level	English	Private organization
Haryana	Faridabad	City Development Plan	City level	Hindi	Private organization
	Gurgoan	Master Plan	City level	English	Development Authority
Delhi	Delhi	Master Plan	City level	English	Development Authority
	Delhi	City Development Plan	City level	Hindi	Private organization
Delhi, Haryana , UP and Rajasthan	National capital Region	Regional Plan	NCR	English	Development Authority
Rajasthan	Jaipur	Master Plan	City level	English	Development Authority
	Jaipur	City Development Plan	City level	English	Private organization
	Jodhpur	Master Plan	City level	English	Development Authority
	Kota	Master Plan	City level	English	Development Authority
Uttar Pradesh	Lucknow	Master Plan	City level	English	Development Authority
	Lucknow	City Development Plan	City level	English	Private organization
	Kanpur	City Development Plan	City level	English	Private organization
	Agra	City Development Plan	City level	English	Private organization
Bihar	Patna	City Development Plan	City level	English	Private organization
	Patna	Master Plan	City level	English	Private organization
	Bodhgaya	City Development Plan	City level	English	Private organization
Manipur	Imphal	City Development Plan	City level	English	Private organization

	Aizawal	City Development Plan	City level	English	Private organization
Tripura	Agartala	City Development Plan	City level	English	Private organization
Meghalaya	Shillong	City Development Plan	City level	English	Private organization
Assam	Guwahati	Master Plan	City level	English	Private organization
	Guwahati	City Development Plan	City level	English	Private organization
West Bengal	Kolkata	City Development Plan	City level	English	Private organization
Jharkhand	Jamshedpur	City Development Plan	City level	English	Private organization
	Dhanbad	City Development Plan	City level	English	Private organization
	Ranchi	City Development Plan	City level	English	Private organization
Orissa	Bhubaneswar	City Development Plan	City level	English	Private organization
Chhattisgarh	Raipur	City Development Plan	City level	English	Private organization
	Raipur	Development Plan	City level	English	Private organization
Madhya Pradesh	Indore	Master Plan	City level	English	Development Authority
	Bhopal	Master Plan	City level	English	Development Authority
	Bhopal	City Development Plan	City level	English	Private organization
Himachal Pradesh	Shimla	City Development Plan	City level	English	Private organization
	Shimla	Master Plan	City level	English	Development Authority
Gujarat	Ahmedabad	City Development Plan	City level	English	Private and Development Authority
	Surat	City Development Plan	City level	English	Private and Development Authority
Maharashtra	Mumbai	Master Plan	City level	English	Development Authority
	Mumbai	City Development Plan	City level	English	Private organization
	Nagpur	City Development Plan	City level	English	Private organization
Andhra Pradesh	Hyderabad	City Development Plan	City level	English	Private organization
	Vishakhapatnam	City Development Plan	City level	English	Private organization
Karnataka	Bangalore	City Development Plan	City level	English	Private organization
Goa	Panji	City Development Plan	City level	English	Private organization
Kerala	Kochi	Development Plan	City level	English	Development Authority
	Thiruvananthapuram	City Development Plan	City level	English	Private organization
Tamil Nadu	Chennai	Master Plan	City level	English	Development Authority
	Chennai	City Development Plan	City level	English	Private organization
	Coimbatore	City Development Plan	City level	English	Private organization
	Madurai	City Development Plan	City level	English	Private organization
Andaman Islands	Port Blair	Master Plan	City level	English	Development Authority

Appendix 3. Performance of spatial plans for various cities across India

City	Type of spatial plan	Overall plan performance	Awareness	Analysis	Action
Jammu	Master Plan	0.06	0.00	0.09	0.08
Shri Nagar	City Development Plan	0.23	0.13	0.33	0.15
Amritsar	Master Plan	0.20	0.00	0.24	0.23
Ludhiana	Master Plan	0.21	0.25	0.24	0.19
Chandigarh	City Development Plan	0.15	0.25	0.12	0.19
Shimla	Master Plan	0.26	0.88	0.18	0.19
Dehradun	Master Plan	0.11	0.13	0.15	0.08
Haridwar	City Development Plan	0.05	0.00	0.03	0.12
Faridabad	City Development Plan	0.08	0.00	0.15	0.04
Gurgoan	Master Plan	0.09	0.00	0.09	0.15
Delhi	Master Plan	0.55	0.25	0.55	0.65
Jaipur	Master Plan	0.27	0.13	0.42	0.15
Jodhpur	Master Plan	0.00	0.00	0.00	0.04
Kota	Master Plan	0.00	0.00	0.00	0.04
Lucknow	City Development Plan	0.17	0.00	0.18	0.23
Kanpur	City Development Plan	0.29	0.13	0.39	0.23
Agra	City Development Plan	0.11	0.00	0.15	0.12
Patna	City Development Plan	0.23	0.00	0.30	0.23
Bodhgaya	City Development Plan	0.20	0.00	0.21	0.27
Imphal	City Development Plan	0.12	0.00	0.15	0.15
Aizawal	City Development Plan	0.14	0.00	0.15	0.19
Agartala	City Development Plan	0.21	0.00	0.30	0.19
Shillong	City Development Plan	0.20	0.00	0.27	0.19
Guwahati	Master Plan	0.29	0.25	0.27	0.35
Kolkata	City Development Plan	0.30	0.00	0.39	0.31
Jamshedpur	City Development Plan	0.14	0.13	0.15	0.15
Dhanbad	City Development Plan	0.24	0.00	0.33	0.23
Ranchi	City Development Plan	0.18	0.00	0.27	0.15
Bhubaneswar	City Development Plan	0.23	0.00	0.33	0.19
Raipur	Master Plan	0.26	0.00	0.36	0.23
Indore	Master Plan	0.09	0.00	0.09	0.15
Bhopal	Master Plan	0.30	0.38	0.30	0.31
Ahmedabad	City Development Plan	0.23	0.13	0.24	0.27
Surat	City Development Plan	0.27	0.13	0.33	0.27
Mumbai	Master Plan	0.42	0.25	0.45	0.46
Nagpur	City Development Plan	0.26	0.13	0.30	0.27
Hyderabad	City Development Plan	0.23	0.00	0.30	0.23
Vishakhapatnam	City Development Plan	0.12	0.00	0.18	0.12

Bangalore	City Development Plan	0.21	0.00	0.21	0.31
Panji	City Development Plan	0.15	0.00	0.21	0.15
Kochi	Master Plan	0.50	0.25	0.52	0.58
Thiruvananthapuram	City Development Plan	0.14	0.00	0.18	0.15
Chennai	Master Plan	0.30	0.25	0.33	0.31
Coimbatore	City Development Plan	0.02	0.00	0.06	0.00
Madurai	City Development Plan	0.11	0.00	0.09	0.19
Port Blair	Master Plan	0.38	0.63	0.30	0.42

Notes: The maximum score for each component of awareness, analysis and action is 1. The maximum performance score for any spatial plan (after standardization) is 1.

Appendix 4. Data source and data preparation

Component's aspects	Indicators	Data source	Data type	Data Preparation Step	Critical range for standardization
Exposure					
Temperature	• Hot days/year (Tmax>30º C) • Mean temperature Increase	• Indian meteorological department, Bangalore and Pune, India. • Directorate of Economics and Statistics (DES), Bangalore, Karnataka, India. • Museum of Vertebrate Zoology, University of California, Berkeley, USA.	• Monthly mean maximum, minimum and average temperature data for one station (1901-2000) • High resolution gridded daily temperature data for Mesoscale Meteorological Studies(1971-2005) • Monthly mean maximum, minimum and average temperature data for four stations (2000-2014) • World Climate Data	• Temperature data were selected for those stations having more than 80% of data availability while 1901-2014 and others were rejected. • For a number of hot days/year indicator focus was given for the past five-year data for the four stations. • Change of mean maximum temperature, mean minimum temperature, and yearly mean temperature for four stations were analysed. • Spatial interpolation of annual mean temperature, numbers of hot days/year data were analysed with the help of ordinary kriging tool under the spatial analyst extension of ArcMap 10 based upon number of points and maximum distance variables. • With the help of math algebra and zonal tool under spatial analyst extension of ArcMap 10 ward wise information extracted from the results of kriging output.	<.25^{0}C 25-.50^{0}C >.50^{0}C <30 days 30-45 days >45 days
precipitation	• Rain range (>830 mm/year) • Number of days/year with	• Indian meteorological department, Bangalore and Pune, India. • Directorat	• Monthly and yearly average rainfall (mm) and rainy days from 6 stations (1901-205) • High resolution gridded daily rainfall data for	• Monthly rainfall data were selected for those stations having more than 80% of data availability while 1901-2014 and others were rejected. • For a number of heavy rainfall days/ year indicators focus was given for the past five-year data for 17 out of 20 stations.	<830 mm 830-950 mm >950 mm <3 days 3-5 days >6 days

	heavy rain (RR >30mm)	e of Economics and Statistics (DES), Bangalore, Karnataka, India. • Museum of Vertebrate Zoology, University of California, Berkeley, USA.	Mesoscale Meteorological Studies (1971-2005) • Monthly rainfall (mm) and rainy days for 20 (2010-2014) • Kriging were also applied to these 4 points • World Climate Data	• Spatial interpolation of annual and monthly rainfall, numbers days with heavy rainfall/year data were analysed with the help of ordinary kriging tool of spatial analyst extension of ArcMap 10 based upon number of points and maximum distance variables. • With the help of math algebra and zonal tool under spatial analyst extension of ArcMap 10 ward wise information extracted from the results of kriging output.	
Sensitivity					
Physical and economic	Area covered by road	• Bangalore development authority, Bangalore. • Bruhat Bengaluru Mahanagara Palike, Bangalore. • Bangalore Metropolitan Transport Corporation, Bangalore. • Karnataka urban infrastructure development and Finance Corporation.	• Road Network Characteristics • Distribution of Roads with Carriageway Widths (Rail Network, Airport) • Vehicle Growth and Composition • Urban land use structure	• Based on land use change analysis, total area identified under road infrastructure. • Accessibility analysis with the help of Flowmap 7.4 and ArcMap 10. • Projection of trip distribution on the main roads and zones in Bangalore based on the 2011 modal split data from Rites. • With the help of math algebra and zonal tool under spatial analyst extension of ArcMap 10 ward wise road infrastructure information was extracted.	<10 % 10-25% >25 %
	High-density area	• Census of India, Bangalore and Delhi, India. • Bangalore	Population at ward level	• Spatial distribution of population according to the census data. • Population density for each ward was calculated with the help of math and zonal tool	<15000 25000 >25000

		development Authority, Bangalore, India. • The Bruhat Bengaluru Mahanagara Palike, Bangalore, India.		under spatial analyst extension of ArcMap 10.	
	Number of slums	• Census of India, Bangalore and Delhi, India. • Bangalore development Authority, Bangalore, India. • The Bruhat Bengaluru Mahanagara Palike, Bangalore, India.	Number of slums, slum population, the gender split at ward level	• Based on municipal data on slums, location of slums was identified. • With the help of zonal tool under spatial analyst extension of ArcMap 10 ward wise pattern of slums and information was extracted.	0 1-5 >5
	Land use change	• Bangalore development Authority, Bangalore, India. • Global Land Cover Facility (GLCF – http://www.landcover.org/), and from the U.S. Geological Survey (USGS) and NASA's Landsat mission website.	Landsat ETM+ and Landsat 8 images for Nov 2000 and June 2014	• With the help of un- supervised classification under spatial analyst extension of Arch Map 10 for both images land cover analysed. • With the help of ground control points and data collected from field digital classification of significant land cover / land use were done and categorized into four principal classes of land cover/ land use with for each time period – vegetation, water , built area and open areas. • Change detection analysis for every land use category were conducted • With the help of math algebra and zonal tool under spatial analyst extension of ArcMap 10 ward wise land use / land cover	<10% 10-25% >25%

				information was extracted.	
	Percentage of people younger than six years	Census of India, Bangalore and Delhi, India.	People younger than six years at ward level	• Spatial distribution of people younger than six years according to the census data. • Percentage of people younger than six years information for each ward was calculated with the help of zonal tool under spatial analyst extension of ArcMap 10.	<10% 10-15% >15%
	Percentage of liveable houses	Census of India, Bangalore and Delhi , India.	Percentage of liveable houses at ward level	• Spatial distribution of percentage of liveable houses according to the census data. • Percentage of liveable houses information for each ward was calculated with the help of zonal tool under spatial analyst extension of ArcMap 10.	<75% 75-90% >90%
Environ mental	Increased fluctuation of the groundwate r level	• Central ground water board, Government of India, India • Census of India, Bangalore and Delhi, India. • Bangalore Urban Metabolism	• Monthly and yearly average rainfall (mm) and rainy days from different stations (1901-2014) • High resolution gridded daily rainfall data for Mesoscale Meteorological Studies (1971-2005)	• Monthly rainfall data were selected for those stations having more than 80% of data availability while 1901-2014 (Focus was for the last ten years), and others were rejected. • Monthly rate of change of rainfall was analysed • Difference of rainfall between pre-monsoon and after monsoon was analysed for past ten years • Spatial interpolation of difference of rainfall between pre-monsoon and after monsoon	<-100 mm -100-200 mm >-200 mm

		Project (BUMP), Indian institute of Management, Bangalore, India.	• Monthly rainfall (mm) and rainy days from 20 stations (2010-2014)	data was done with the help of ordinary kriging tool under spatial analyst extension of ArcMap 10 based upon the number of points and maximum distance variables. • With the help of math algebra and zonal tool under spatial analyst extension of ArcMap 10 ward wise difference of rainfall between pre-monsoon and after monsoon data information extracted.	
	Loss of lakes and wetland area	• The Bruhat Bengaluru Mahanagara Palike, Bangalore, India. • Bangalore development Authority, Bangalore, India. • Lake development Authority Bangalore, India. • Primary survey.	Landsat ETM+ image of Nov 2000 and Landsat 8 image of June 2014	• Based on land use change analysis, total area identified under lakes and wetland area. • Rate of change of area under lakes and wetland area were analysed • With the help of math algebra and zonal tool under spatial analyst extension of ArcMap 10 ward wise loss of lakes and wetland area information was extracted	<20% 20-30% >30%
Adaptive Capacity					
Socio-economic	Percentage of household having banking facilities	• Census of India, Bangalore and Delhi, India. • National Sample Survey Office Bangalore, India. • Bangalore development authority, Bangalore, India.	Percentage of households having banking facilities at ward level	• Spatial distribution of percentage of households having banking facilities according to the census data. • Percentage of households having banking facilities information for each ward was calculated with the help of zonal tool under spatial analyst extension of ArcMap 10.	<50% 50-75% >75%
	Percentage of household	• Census of India, Bangalore and Delhi , India.	Percentage of households having housing	• Spatial distribution of percentage of households having housing ownership	<50% 50-75% >75%

	having housing ownership	• National Sample Survey Office Bangalore, India. • Bangalore development authority, Banga lore, India.	ownership at ward level	according to the census data. • Percentage of households having housing ownership information for each ward was calculated with the help of zonal tool under spatial analyst extension of ArcMap 10.	
	Percentage of household having all kind asset ownership	• Census of India, Bangalore and Delhi , India. • National Sample Survey Office Bangalore, India. • Bangalore development authority, Banga lore, India.	Percentage of households having all kind asset ownership at ward level	• Spatial distribution of percentage of households having all kind asset ownership according to the census data. • Percentage of households having all kind asset ownership information for each ward was calculated with the help of zonal tool under spatial analyst extension of ArcMap 10.	<50% 50-75% >75%
	Percentage of people who are literate	• Census of India, Bangalore and Delhi , India. • National Sample Survey Office Bangalore, India. • Bangalore development authority, Banga lore, India.	Percentage of people who are literate at ward level	• Spatial distribution of percentage of people who are literate according to the census data. • Percentage of people who are literate information for each ward was calculated with the help of zonal tool under spatial analyst extension of ArcMap 10.	<75% 75-90% >90%
Provision of basic facilities	Percentage of household having drinking water connection	• Census of India, Bangalore and Delhi , India. • National Sample Survey Office Bangalore, India. • Bangalore development authority, Banga lore, India.	Percentage of households having drinking water connection at ward level	• Spatial distribution of percentage of households having drinking water connection according to the census data. • Percentage of households having drinking water connection information for each ward was calculated with the help of zonal tool under spatial analyst extension of ArcMap 10.	<75% 75-90% >90%
	Percentage of	• Census of India, Bangalore and	Percentage of households	• Spatial distribution percentage of households having waste	<75% 75-90%

	household having waste water drainage connection	Delhi , India. • National Sample Survey Office Bangalore, India. • Bangalore development authority, Banga lore, India.	having waste water drainage connection at ward level	water drainage connection according to the census data. • Percentage of households having waste water drainage connection information for each ward was calculated with the help of zonal tool under spatial analyst extension of ArcMap 10.	>90%
	Percentage of household connected to efficient cooking fuel	• Census of India, Bangalore and Delhi, India. • National Sample Survey Office Bangalore, India. • Bangalore development authority, Banga lore, India.	Percentage of households connected to efficient cooking fuel at ward level	• Spatial distribution percentage of households connected to efficient cooking fuel according to the census data. • Percentage of households connected to efficient cooking fuel information for each ward was calculated with the help of zonal tool under spatial analyst extension of ArcMap 10.	<75% 75-90% >90%
	Percentage of area having access to road	• Census of India, Bangalore and Delhi, India • National Sample Survey Office Bangalore, India • Bangalore development authority, Banga lore, India	Roads networks Land use change, 2009 to 2014	• Based on land use change analysis, total area identified under road infrastructure. • With the help of zonal tool under spatial analyst extension of ArcMap 10 ward wise percentage of area having access to road information was extracted	<5% 5-10% >10%
Ecologic al	Green space/ per person	• Census of India, Bangalore and Delhi, India • Bangalore development Authority, Bangalore, India. • Global Land Cover Facility (GLCF – http://www.landc over.org/), and from the U.S. Geological Survey (USGS)	Land use change, 2009 - 2014 Population at ward level	• Based on land use change analysis, total area identified under vegetation land use category. • With the help of zonal tool under spatial analyst extension of ArcMap 10 ward wise area vegetation land use information was extracted • People having green space information for each ward was calculated with the help of zonal tool under spatial analyst extension of ArcMap 10.	<10 sq/m 10-20 sq/m >20 sq/m

		and NASA's Landsat mission website.			
	Percentage of area under lakes	• Bangalore development Authority, Bangalore, India. • Lake development Authority Bangalore, India. • Census of India, Bangalore and Delhi, India	Land use change, 2009 - 2014	• Based on land use change analysis, total area identified under lakes and wetland area. • Rate of change of area under lakes and wetland area were analysed • With the help of math algebra and zonal tool under spatial analyst extension of ArcMap 10 ward wise loss of lakes and wetland area information was extracted	<1% 1-3% >3%

Appendix 5. Ward wise vulnerability assessment for climate change of Bangalore city (Outcome values are scaled on 0-1 range)

Ward No.	Ward name	Vulnerability	Exposure	Sensitivity	Impact	Adaptive capacity
1	Kempegowda	0.71	1.00	0.47	0.71	0.54
2	Chowdeswari	0.71	1.00	0.47	0.71	0.49
3	Atturu	0.66	0.91	0.47	0.66	0.44
4	Yelahanka Satellite Town	0.66	0.91	0.50	0.66	0.54
5	Jakkuru	0.71	1.00	0.47	0.75	0.49
6	Thanisandra	0.66	0.81	0.44	0.62	0.44
7	Byatarayanapura	0.66	0.81	0.44	0.57	0.49
8	Kodigehalli	0.66	0.81	0.44	0.62	0.44
9	Vidyaranyapura	0.61	0.81	0.41	0.57	0.54
10	Dodda Bommasandra	0.61	0.81	0.41	0.57	0.54
11	Kuvempu Nagar	0.66	0.81	0.47	0.66	0.49
12	Shettihalli	0.61	0.81	0.44	0.57	0.49
13	Mallasandra	0.66	0.81	0.44	0.62	0.44
14	Bagalakunte	0.66	0.81	0.47	0.62	0.44
15	T Dasarahalli	0.61	0.81	0.41	0.52	0.49
16	Jalahalli	0.61	0.81	0.44	0.57	0.54
17	J P Park	0.61	0.81	0.41	0.52	0.49
18	Radhakrishna Temple	0.61	0.81	0.41	0.52	0.44
19	Sanjaya Nagar	0.61	0.68	0.41	0.52	0.44
20	Ganga Nagar	0.61	0.68	0.44	0.57	0.44
21	Hebbala	0.61	0.68	0.44	0.57	0.44
22	Vishwanath Nagenahalli	0.61	0.81	0.44	0.57	0.49
23	Nagavara	0.66	0.81	0.44	0.62	0.44
24	HBR Layout	0.71	0.81	0.54	0.66	0.49
25	Horamavu	0.66	0.91	0.47	0.62	0.44
26	Ramamurthy Nagar	0.71	0.91	0.47	0.57	0.44
27	Banasavadi	0.61	0.68	0.47	0.52	0.44
28	Kammanahalli	0.61	0.68	0.44	0.48	0.44
29	Kacharkanahalli	0.61	0.68	0.50	0.52	0.44
30	Kadugondanahalli	0.66	0.68	0.54	0.62	0.49
31	Kushal Nagar	0.61	0.68	0.57	0.71	0.49
32	Kaval Bairasandra	0.61	0.68	0.44	0.48	0.49
33	Manorayanapalya	0.61	0.68	0.41	0.52	0.49
34	Gangenahalli	0.61	0.68	0.41	0.52	0.44
35	Aramane Nagara	0.55	0.68	0.41	0.52	0.59
36	Mattikere	0.66	0.81	0.47	0.57	0.44

37	Yeshwanthpura	0.66	0.81	0.47	0.66	0.49
38	HMT Ward	0.61	0.68	0.47	0.62	0.44
39	Chokkasandra	0.66	0.81	0.47	0.62	0.44
40	Dodda Bidarakallu	0.61	0.68	0.47	0.62	0.49
41	Peenya Industrial Area	0.61	0.68	0.41	0.52	0.44
42	Lakshmi Devi Nagar	0.66	0.68	0.50	0.66	0.49
43	Nandini Layout	0.61	0.68	0.44	0.57	0.44
44	Marappana Palya	0.66	0.81	0.54	0.75	0.44
45	Malleswaram	0.66	0.81	0.57	0.57	0.44
46	Jayachamarajendra Nagar	0.61	0.68	0.44	0.57	0.44
47	Devara Jeevanahalli	0.66	0.68	0.54	0.66	0.44
48	Muneshwara Nagar	0.66	0.68	0.57	0.71	0.49
49	Lingarajapura	0.66	0.68	0.50	0.57	0.49
50	Benniganahalli	0.61	0.68	0.47	0.52	0.49
51	Vijnanapura	0.71	0.91	0.50	0.57	0.44
52	K R Puram	0.71	1.00	0.47	0.62	0.49
53	Basavanapura	0.71	0.91	0.47	0.66	0.44
54	Hudi	0.71	1.00	0.47	0.75	0.49
55	Devasandra	0.71	0.91	0.57	0.66	0.44
56	A Narayanapura	0.71	0.91	0.50	0.57	0.44
57	C V Raman Nagar	0.61	0.81	0.47	0.57	0.49
58	New Tippasandara	0.61	0.91	0.41	0.57	0.44
59	Maruthi Seva Nagar	0.61	0.68	0.57	0.66	0.49
60	Sagayarapuram	0.66	0.68	0.50	0.57	0.49
61	S K Garden	0.61	0.68	0.47	0.52	0.49
62	Ramaswamy Palya	0.66	0.68	0.50	0.62	0.49
63	Jayamahal	0.66	0.68	0.70	0.66	0.49
64	Rajamahal Guttahalli	0.61	0.68	0.47	0.52	0.44
65	Kadu Malleshwar	0.61	0.68	0.44	0.52	0.44
66	Subramanya Nagar	0.61	0.68	0.44	0.48	0.44
67	Nagapura	0.61	0.68	0.41	0.48	0.44
68	Mahalakshimpuram	0.61	0.68	0.41	0.52	0.44
69	Laggere	0.66	0.68	0.47	0.62	0.44
70	Rajagopal Nagar	0.66	0.68	0.60	0.62	0.44
71	Hegganahalli	0.66	0.68	0.44	0.57	0.44
72	Herohalli	0.66	0.68	0.47	0.62	0.44
73	Kottegepalya	0.61	0.68	0.60	0.62	0.44
74	Shakthi Ganapathi Nagar	0.61	0.68	0.47	0.57	0.44
75	Shankar Matt	0.61	0.68	0.44	0.52	0.44
76	Gayithri Nagar	0.61	0.68	0.50	0.57	0.44
77	Dattatreya Temple	0.61	0.68	0.47	0.52	0.44
78	Pulikeshinagar	0.61	0.68	0.70	0.52	0.44
79	Sarvagna Nagar	0.61	0.68	0.54	0.62	0.49
80	Hoysala Nagar	0.61	0.68	0.44	0.52	0.44
81	Vijnana Nagar	0.61	0.91	0.47	0.57	0.44
82	Garudachar Playa	0.61	0.91	0.44	0.66	0.44

83	Kadugodi	0.61	0.91	0.44	0.66	0.49
84	Hagadur	0.61	0.81	0.44	0.66	0.44
85	Dodda Nekkundi	0.61	0.91	0.41	0.57	0.49
86	Marathahalli	0.61	0.91	0.47	0.66	0.44
87	HAL Airport	0.61	0.81	0.44	0.66	0.49
88	Jeevanbhima Nagar	0.61	0.81	0.44	0.62	0.49
89	Jogupalya	0.55	0.68	0.41	0.57	0.44
90	Halsoor	0.61	0.68	0.50	0.57	0.44
91	Bharathi Nagar	0.66	0.68	0.66	0.57	0.44
92	Shivaji Nagar	0.66	0.68	0.70	0.57	0.44
93	Vasanth Nagar	0.55	0.68	0.44	0.57	0.59
94	Gandhinagar	0.71	0.81	0.66	0.62	0.44
95	Subhash Nagar	0.66	0.81	0.66	0.66	0.49
96	Okalipuram	0.66	0.68	0.57	0.66	0.44
97	Dayananda Nagar	0.66	0.68	0.57	0.52	0.44
98	Prakash Nagar	0.66	0.81	0.54	0.57	0.44
99	Rajaji Nagar	0.61	0.81	0.57	0.48	0.44
100	Basaveshwara Nagar	0.61	0.68	0.44	0.57	0.44
101	Kamakshipalya	0.61	0.68	0.41	0.52	0.44
102	Vrisabhavathi Nagar	0.61	0.68	0.47	0.57	0.44
103	Kaveripura	0.61	0.68	0.41	0.48	0.44
104	Govindaraja Nagar	0.61	0.68	0.44	0.57	0.44
105	Agrahara Dasarahalli	0.66	0.68	0.50	0.57	0.44
106	Dr. Raj Kumar Ward	0.66	0.68	0.57	0.62	0.44
107	Shivanagara	0.61	0.68	0.54	0.48	0.44
108	Sriramamandir	0.66	0.68	0.60	0.52	0.44
109	Chickpete	0.66	0.81	0.66	0.62	0.54
110	Sampangiram Nagar	0.61	0.68	0.44	0.48	0.59
111	Shantala Nagar	0.61	0.68	0.47	0.62	0.59
112	Domlur	0.55	0.63	0.41	0.48	0.44
113	Konena Agrahara	0.61	0.81	0.47	0.66	0.44
114	Agaram	0.61	0.81	0.47	0.66	0.59
115	Vannarpet	0.61	0.81	0.50	0.66	0.49
116	Nilasandra	0.66	0.68	0.50	0.62	0.49
117	Shanthi Nagar	0.66	0.68	0.60	0.66	0.44
118	Sudham Nagara	0.66	0.68	0.57	0.66	0.44
119	Dharmaraya Swamy Temple	0.66	0.68	0.57	0.57	0.54
120	Cottonpete	0.66	0.81	0.50	0.66	0.44
121	Binnipete	0.66	0.68	0.60	0.52	0.44
122	Kempapura Agrahara	0.66	0.68	0.60	0.62	0.44
123	Vijayanagar	0.66	0.68	0.57	0.57	0.44
124	Hosahalli	0.61	0.68	0.44	0.57	0.44
125	Marenahalli	0.61	0.68	0.47	0.62	0.44
126	Maruthi Mandir	0.61	0.68	0.41	0.57	0.44
127	Mudalapalya	0.61	0.68	0.50	0.62	0.44
128	Nagarabhavi	0.61	0.68	0.50	0.57	0.44

129	Jnana Bharathi	0.55	0.68	0.44	0.52	0.54
130	Ullalu	0.61	0.68	0.50	0.52	0.44
131	Nayandahalli	0.61	0.68	0.50	0.57	0.44
132	Attiguppe	0.61	0.68	0.41	0.52	0.44
133	Hampi Nagar	0.61	0.68	0.41	0.48	0.44
134	Bapuji Nagar	0.61	0.68	0.44	0.48	0.44
135	Padarayanapura	0.61	0.68	0.47	0.62	0.49
136	Jagajivanaramnagar	0.61	0.68	0.47	0.57	0.44
137	Rayapuram	0.66	0.68	0.47	0.57	0.49
138	Chalavadipalya	0.71	0.68	0.70	0.57	0.49
139	K R Market	0.66	0.68	0.54	0.66	0.49
140	Chamrajapet	0.61	0.68	0.50	0.57	0.49
141	Azad Nagar	0.61	0.68	0.50	0.57	0.49
142	Sunkenahalli	0.61	0.68	0.57	0.52	0.44
143	Vishveshwara Puram	0.61	0.68	0.41	0.52	0.44
144	Siddapura	0.66	0.68	0.50	0.66	0.49
145	Hombegowda Nagara	0.61	0.68	0.50	0.57	0.49
146	Lakkasandra	0.66	1.00	0.50	0.62	0.44
147	Adugodi	0.71	1.00	0.44	0.66	0.49
148	Ejipura	0.61	0.81	0.41	0.57	0.44
149	Varthuru	0.61	0.81	0.57	0.62	0.44
150	Bellanduru	0.61	0.91	0.44	0.66	0.54
151	Koramangala	0.66	1.00	0.44	0.66	0.54
152	Suddagunte Palya	0.66	1.00	0.41	0.62	0.44
153	Jayanagar	0.66	0.68	0.54	0.52	0.44
154	Basavanagudi	0.66	0.68	0.57	0.48	0.44
155	Hanumanth Nagar	0.61	0.68	0.44	0.48	0.44
156	Srinagar	0.61	0.68	0.47	0.48	0.49
157	Gali Anjenaya Temple	0.61	0.68	0.44	0.52	0.44
158	Deepanjali Nagar	0.61	0.68	0.47	0.57	0.44
159	Kengeri	0.61	0.68	0.47	0.52	0.44
160	Rajarajeshwari Nagar	0.55	0.68	0.47	0.48	0.54
161	Hosakerehalli	0.61	0.68	0.47	0.52	0.44
162	Girinagar	0.61	0.68	0.44	0.48	0.44
163	Katriguppe	0.61	0.68	0.47	0.48	0.44
164	Vidyapeeta ward	0.61	0.68	0.57	0.57	0.44
165	Ganesh Mandir	0.61	0.68	0.47	0.52	0.44
166	Karisandra	0.66	0.68	0.47	0.62	0.49
167	Yediyur	0.61	0.68	0.41	0.48	0.44
168	Pattabhiram Nagar	0.66	1.00	0.44	0.66	0.44
169	Byrasandra	0.66	0.68	0.50	0.62	0.44
170	Jayanagar East	0.71	1.00	0.44	0.66	0.44
171	Gurappanapalya	0.66	1.00	0.41	0.57	0.44
172	Madivala	0.61	1.00	0.41	0.57	0.49
173	Jakkasandra	0.61	1.00	0.41	0.57	0.44
174	HSR Layout	0.61	0.81	0.41	0.57	0.49

175	Bommanahalli	0.66	0.91	0.44	0.66	0.49
176	BTM Layout	0.66	1.00	0.41	0.57	0.49
177	J P Nagar	0.71	1.00	0.44	0.62	0.49
178	Sarakki	0.66	1.00	0.41	0.62	0.44
179	Shakambari Nagar	0.66	1.00	0.44	0.66	0.49
180	Banashankari Temple	0.66	1.00	0.50	0.66	0.49
181	Kumaraswamy Layout	0.61	1.00	0.41	0.48	0.44
182	Padmanabha Nagar	0.61	0.68	0.41	0.52	0.44
183	Chikkalsandra	0.61	0.68	0.47	0.52	0.44
184	Uttarahalli	0.66	0.68	0.60	0.52	0.44
185	Yelchenahalli	0.71	1.00	0.44	0.66	0.49
186	Jaraganahalli	0.66	1.00	0.41	0.62	0.44
187	Puttenahalli	0.66	0.91	0.41	0.57	0.49
188	Bilekhalli	0.66	0.91	0.41	0.57	0.49
189	Hongasandra	0.66	0.91	0.44	0.62	0.49
190	Mangammanapalya	0.66	0.81	0.44	0.62	0.44
191	Singasandra	0.66	0.81	0.50	0.62	0.44
192	Begur	0.71	0.91	0.60	0.80	0.44
193	Arakere	0.66	0.91	0.47	0.57	0.49
194	Gottigere	0.71	0.91	0.57	0.75	0.44
195	Konankunte	0.66	0.91	0.41	0.57	0.49
196	Anjanapura	0.71	0.91	0.54	0.71	0.44
197	Vasanthpura	0.71	1.00	0.50	0.66	0.49
198	Hemmigepura	0.61	0.68	0.50	0.52	0.54

Appendix 6. House Hold Survey

House Hold Survey

Name :
Area /Village:

Sex 1- F, 2 -M	**Age** 1- <16, 2 ->16	**Education**	**Occupation** 1 – Farmer, 2- Agriculture labour, 3- Business, 4- Daily Wage Labour, 5- Service and 6- Others	**Social group** 1- General, 2- SC 3- ST, 4-BC/OBC	**Religion** 1- Hindu, 2- Buddhist 3- Christian and 4- Other	**Family income** 1-<40K, 2- 40K - 60K, 3- 60K - 80K, and 4- > 80K

No of Households	**Sex**	**Age**	**Occupation**	**Family Member involved in migration/seasonal Labour**
1				
2				
n				

Key aspects and criteria

Aspects	Criteria	Questions	1	2	3	4	5	Remarks
Housing condition	**Housing Ownership**	**Do you own a house?**	No				Yes	
	House location	**Where is your house located?**	slums	Near main road	Near industry	Village	Good residential area	
	Overcrowding	**How many people are staying in one room?**	> 3		2		1	
	Durable structure	**Housing characteristics/ structure**	shack	Traditional stick house/temporary	Semi permanent structure	Improved house permanent structure	permanent structure	

Housing facilities	**Access to water**	**What is the source of drinking water?**	Well/lake		Water tanker	Piped water	Piped water + water purifier at home	
	Type of sanitation facility?	**What type of toilet you use?**	No toilet	Govt developed public facilities	pit toilet		Flush toilet	
	Bathing facilities?	**What type of bathing facilities do you have?**	Unprotected well and lake	Protected well	Street vendors	Piped water in the community/plot	Piped water inside the house	
		What is the distance to the nearest water source?	<50m	50-100m	100-500m	500-1000m	>1000m	
	Kitchen	**Do you have kitchen within the housing unit?**	No				Yes	
	Energy for cooking	**What is the main source of cooking at your house?**	firewood	dung		Bottled Gas/LPG	Electricity	
	Electricity	**Do you have electricity connection at you home?**	No		Coal and paraffin	Electricity connection	Solar and wind	
House hold facilities	**Mobility**	**Do you have car or two- wheeler?**	No	cycle	Scooter	Bike	Car	
	Networking	**Do you have telephone or mobile?**	No				Yes	
	Awareness	**Do you receive the newspaper or have a television?**	No				Yes	
		Do you know local schemes, policies and development work?						
	Material	**Do you have a refrigerator?**	No				Yes	
		Do you have a washing machine?	No				Yes	
		Do you have AC?	No				Yes	
Economics structure	**Banking facilities**	**Do you have bank or post office account?**	No				Yes	
		Do you have access to credit (loan)?	No				Yes	

		What is the source of credit?	NA	Multiple source	Private money lenders	SHGs	Banks/Post Office	
	Insurance and social security	**Does your family have health and disaster insurance?**	No				Yes	
		Does your family have BPL/APL card?	NA			BPL	APL	
		Are you family benefiting from social security scheme (PDS/NREGA/MDM/ICDS. Etc..), If yes which scheme	Other	Forest land	Leased land	Small Farm Land (Farmer Less than 5 Acre).	Large Farmland (Farmer more than 5 Acre)	
State deprivation	**Education facilities**	**How far is the nearest school?**	2-2.5km	1.5-2km	1-1.5km	500-1000m	500m	
	Health facilities	**How far is the nearest health centre?**	2-2.5km	1.5-2km	1-1.5km	500-1000m	500m	
	Hazard Facilities	**How far is the fire bridge services centre?**	2-2.5km	1.5-2km	1-1.5km	500-1000m	500m	
	Physical infrastructure	**Do you have the main road near your house?**	No				Yes	
		Do you have public transportation near your community?	NO				Yes	
Land and food security	**Food security**	**What type of land owned by your family?**	N.A	Multiple Type Land	Waste Land	Un-Irrigated Land	Irrigated Land	
		What is the major cultivation do you have in your land?	Grains, Cereals	Vegetables	Fruits and Flowers	Medicinal/ Aromatic Plants	Multiple Crop or cash crops	
		Are you using any of the modern technologies for increasing your yield?	No				Yes	
		What type of seeds do you use in	NA	GM Seeds	High Hybrid	Yield seeds	Traditional	

		your agriculture land			Seeds		Seeds	
		What are the non-farm based activities do you family practice (LIVESTOCK)	NA	Beekeeping and Fishery	Piggery and Poultry	Dairy	Multiple	
		Is any member of the House Hold received any training In agriculture practices?	No				Yes	
		For how many month you have food security?	Less than	3 Months,	6 Months	9 Months	12 Months	
Environment and nature	**Land use change and**	**Do you observe any land use change in your surrounding environment?**	Major changes		Some		No change	
		What are the services you gain from you surrounding environment and nature?						
		Have you observed any wildlife conflict?	Yes		Some time		No	
Climate Variables	**Exposure and impacts**	**Have you observed change in climate and weather pattern? If yes what?**	No		Some time		Yes	
		What are the major impacts of climate change?	Seasonal change	Forest fire	Drought, flooding and landslides	Loss of agriculture production	Loss of life and physical asset	

What are the local government organization and communities' intervention before and post-disaster events?

Key observations: