TECHNICAL REPORT

Economic Impact Assessment of Climate Change in Key Sectors in Nepal

Government of Nepal
Ministry of Science, Technology and Environment (MoSTE)
April 2014

Integrated Development Society Nepal
IDS-Nepal

Global Climate Adaptation Partnership

PRACTICAL ACTION
Consulting

Project Study Team

This project was led by the Integrated Development Society Nepal (IDS-Nepal), working with Practical Action Consulting (PAC) in Nepal and the Global Climate Adaptation Partnership (GCAP) in the UK.

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The project 'Economic Impact Assessment of Climate Change in Key Sectors in Nepal' was undertaken at the request of the Government of Nepal. The project received guidance throughout from the Project Steering Committee. It originated to address the target included in the Climate Change Policy 2011: the assessment of losses and benefits from climate change in various geographical areas and development sectors by 2013. The project and final technical report underwent an international peer review. The views expressed in the report are entirely those of the study team and do not necessarily reflect the views of the Government of Nepal.

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Technical Report

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Acronyms

A1B	Medium high emission scenario from the IPCC SRES
ADEPT-Nepal	Association for the Development of Environment and People in Transition Nepal
ADB	Asian Development Bank
AEPC	Alternative Energy Promotion Centre
AEZ	Agro-ecological Zone
AIT	Asian Institute of Technology
APEC	Asia-Pacific Economic Cooperation
BCM	Billion Cubic Metres
CBS	Central Bureau of Statistics
CCC-M	Climate Change Council-Member
CCD	Climate Compatible Development
CDDE	Capacity Development for Development Effectiveness
CDKN	Climate and Development Knowledge Network
CECI	Centre for International Studies and Cooperation
CEN	Clean Energy Nepal
CGE	Computable General Equilibrium
COP	Conference of Parties
CRED	Centre for Research on the Epidemiology of Disasters
CSAG	Climate Systems Analysis Group
CVT	Coordinated Varietal Trail
DFID	Department for International Development
DGIS	Directorate-General for International Cooperation
DHM	Department of Hydrology and Meteorology
DLS	Department of Livestock Services
DRILP-AF	Decentralized Rural Infrastructure and Livelihood Project-Additional Funding
DRR	Disaster Risk Reduction
DSCWM	Department of Soil Conservation and Water Management
DSSAT	Decision Support System for Agrotechnology Transfer
DWIDP	Department of Water Induced Disaster Prevention
EACC	Economics of Adaptation to Climate Change
ENS	Energy Not Served
EWS	Early Warning System
FAO	Food and Agriculture Organization

FECOFUN	Federation of Community Forest Users, Nepal
GCAP	Global Climate Adaptation Partnership
GCISC	Global Change Impact Studies Centre
GCM	General Circulation Model
GDP	Gross Domestic Product
GFDRR	Global Facility for Disaster Reduction and Recovery
GHG	Green House Gas
GIEWS	Global Information and Early Warning System
GLOF	Glacial Lake Outburst Flood
GoN	Government of Nepal
GWH	Giga Watt Hour
HICAP	Himalayan Climate Change Adaptation Programme
HIMAWANTI	Himalayan Grassroots Women's Natural Resource Management Association
ICHARAM	International Centre for Water Hazard and Risk Management
ICIMOD	International Centre for Integrated Mountain Development
IDS	Integrated Development Society Nepal
IFF	Investment and Financial Flow
IIASA	International Institute for Applied Systems Analysis
IITM	Indian Institute for Tropical Meteorology
IPCC	Intergovernmental Panel on Climate Change
IPP	Independent Power Producer
IPRAD	Institute for Policy Research and Development
ISET	Institute for Social and Environmental Transition
IUCN	International Union for Conservation of Nature
KU	Kathmandu University
KWh	Kilowatts per hour
LAPA	Local Adaptation Plans of Action
LOLP	Loss of Load Probability
LWRB	Lower West Rapti Basin
MoA	Ministry of Agriculture
MoAC	Ministry of Agriculture and Cooperatives
MoAD	Ministry of Agricultural Development
MoEn	Ministry of Energy
MoEnv	Ministry of Environment
MoEST	Ministry of Environment, Science and Technology
MoF	Ministry of Finance
MoFSC	Ministry of Forests and Soil Conservation

MoHA	Ministry of Home Affairs
MoSTE	Ministry of Science, Technology and Environment
MSFP	Multi Stakeholder Forestry Programme
MUAN	Municipal Association of Nepal
MW	Megawatt
NAM	North American Mesoscale
NAP	National Agricultural Policy
NAPA	National Adaptation Programme of Action
NARC	Nepal Agricultural Research Council
NAST	Nepal Academy of Science and Technology
NCCKMC	Nepal Climate Change Knowledge Management Centre
NCVST	Nepal Climate Vulnerability Study Team
NDRI	Nepal Development Research Institute
NEA	Nepal Electricity Authority
NeKSAP	Nepal Khadya Surakshya Anugaman Pranali
NPC	National Planning Commission
NRRC	Nepal Risk Reduction Consortium
NSDRM	National Strategy for Disaster Risk Management
NWP	National Water Plan
NWS	National Water Strategy
OECD	Organization for Economic Co-operation and Development
OFDA	Office of Foreign Disaster Assistance
PAC	Practical Action Consulting
PFM	Public Financial Management
PPCR	Pilot Project for Climate Resilience
PPP	Purchasing Power Parity
PV	Present Value
PWRI	Public Work Research Institute
RCM	Regional Climate Models
RECC	Regional Economics of Climate Change studies
REDD	Reducing Emissions from Deforestation and forest Degradation
RoR	Run of River
SADKN	South Asian Disaster Knowledge Network
SALM	Sustainable Agricultural Land Management
SARI	South Asian Rural Initiative
SPCR	Strategic Programme for Climate Resilience
SRES	Special Report on Emission Scenarios (IPCC)

SREX	Managing Risks of Extreme Events & Disasters to Advance Climate Change Adaptation (IPCC)
SWAT	Soil and Water Assessment Tool
TU	Tribhuvan University
UCT	University of Cape Town
UN	United Nations
UNDP	United Nations Development Programme
UNEP	United Nations Environment Programme
UNESCO	United Nations Educational, Scientific, and Cultural Organization
UNFCCC	United Nations Framework Convention on Climate Change
UNWFP	United Nations World Food Programme
USAID	United States Agency for International Development
VDC	Village Development Committee
VOLL	Value of Lost Load
VPF	Value of Prevented Fatality
VSL	Value of Statistical Life
WASP	Wien Automatic Simulation Planning
WECS	Water and Energy Commission Secretariat
WFP	World Food Programme
WIDMP	Water Induced Disaster Management Policy
WRF	Weather Research and Forecasting
WRS	Water Resources Strategy
WSS	Water Supply and Sanitation
WTP	Willingness to Pay
WWF	World Wildlife Fund
YSEF	Youth and Small Entrepreneurs Small Employment Fund

Government of Nepal
Ministry of Science, Technology and Environment

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Foreword

The Fifth Assessment Report of Intergovernmental Panel on Climate Change has shown that climate change is real and its impacts are serious. Due to its low level of development and dependence of its people on natural resources for their livelihoods, Nepal is extremely sensitive to the adverse impacts of climate change. In this context, the Government of Nepal has given high priority to climate agenda, with the formulation of Climate Change Policy, National Adaptation Programmes of Action, National Framework on Local Adaptation Plans of Action, and appropriate institutional arrangements and programmes. One important initiative in this regard is the study project on "Economic Impact Assessment of Climate Change in Key Sectors in Nepal". This project was designed to directly address one of the targets set by the Climate Change Policy.

This publication is the summary of the main report and includes the key findings of the study which was conducted by a consortium consisting of Integrated Development Society Nepal, Practical Action Consulting Limited, Nepal and Global Climate Adaptation Partnership, UK, over the period of two years. Such a multidimensional study by its very nature, has limitations specially in a country like Nepal where data are either lacking or inadequate or are not available in disaggregated form. Despite this and the uncertainty inherent in future projection of climate impacts, the study team has come up with a useful report that highlights the impacts and the deficit in adaptation to climate change impacts. We hope this report will serve as a valuable addition to the knowledge base on impacts of climate change and will contribute to policy making and programme formulation.

This study is the first of its kind and we hope it will create a basis for future studies covering other sectors of the economy. The methodology followed could also be useful for conducting similar studies in other parts of the world.

On behalf of Ministry of Science, Technology and Environment (MoSTE), I thank the efforts of the team of experts involved in the study and members of the Steering Committee for guiding the study. I also appreciate the funding support of Climate and Development Knowledge Network.

The views expressed in this summary report and the main report are those of the study team and are not necessarily those of MoSTE, Government of Nepal.

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Acknowledgement

This study has assessed economic impacts of climate change for a number of key risks areas in Nepal: the productivity of major agricultural crops; hydro-electricity generation, and water-induced disasters. The study brought together a wide range of multi-disciplinary expertise from local, regional and international level to accomplish this study.

The study has involved the cooperation of many individuals and institutions.

We sincerely acknowledge the support and guidance of the Government of Nepal through the Project Steering Committee coordinated by the Ministry of Science, Technology and Environment. This included contributions and support from all the ministerial representatives on the Committee, including the coordinators (initially Mr. Batu Krishna Uprety, and present coordinator Mr. Prakash Mathema) and the secretaries of MoSTE (Dr. Krishna Chandra Paudel, present secretary of MoSTE, and Secretaries Dr. Som Lal Subedi, Mr. Keshav Prasad Bhattarai, and Mr. Krishna Gyawali).

We also express our sincere thanks to the individual experts of the technical expert groups.

We would also like to thank CDKN who entrusted us with this opportunity, notably Ms. Elizabeth Gogoi, Project Manager Asia and Mr. Ram Chandra Khanal, Nepal Country Coordinator. We also appreciate the insightful views of our national and international peer reviewers: Elizabeth Gogoi, Charlotte Finlay, Ram Chandra Khanal, Lit Ping Low, Dr. Qamaruz Zaman Chaudhry and Victoria Cox from CDKN; Dr. Ganesh Raj Joshi and Dr. Timothy James Taylor, independent international reviewers; and Dr. K. P. Pant independent national reviewer.

We would like to thank the Indian Institute of Tropical Meteorology (IITM) Pune and Dr. R. Krishnan, Executive Director, Centre for Climate Change Research (CCCR) and Dr. Savita Patwardhan who provided us with the climate projection data used in the study. We also acknowledge the Department of Hydrology, MoSTE; National Agriculture Research Centre, and Nepal Electricity Authority for the information we received for the study.

We are also extremely grateful for contribution of the entire study team - Dr. Dinesh Chandra Devkota; Dr. Tara Nidhi Bhattarai; Mr. Adarsha Pokhrel; Dr. Divas Basnet; Mr. Gopal Babu Bhattarai; Mr. Alok Sharma; Mr. Rishesh Man Singh Amatya; Mr. Prakash Koirala; (PAC) Prof. Dr. Ram Manohar Shrestha; Dr. Michelle Slaney; Mr. Gehendra Bahadur Gurung; Ms. Moushumi Shrestha; Mr. Apar Paudyal; (GCAP); Paul Watkiss (Technical Leader); Matt Savage; Thomas E. Downing; Alistair Hunt.

We appreciate the contribution of office support team of IDS Nepal, PAC Nepal, and GCAP and field researchers involved in the case studies. Last but not least we are grateful to the communities of Banke, Kaski and Mustang who provided us their valuable time, information and shared their experience during the case study period.

Finally on behalf of the consortium, we hope that the collective efforts translated into study findings will serve the study purpose and help in the development/upscale/finetune climate resilient policies and programmes in Nepal.

Prof. Dr. Govind Nepal
Study Team Leader
On behalf of Consortium Partners (IDS Nepal, PAC and GCAP)

Prabha Pokhrel
Chairperson, IDS Nepal

April 23, 2014

Key Messages

This study provides estimations of the impact and economic cost of climate change for a number of key risks in Nepal: agriculture, hydro-electricity and water-induced disasters. The key findings are summarised below.

Nepal currently suffers high economic costs due to current climate variability and extreme events

- The economy of Nepal and the livelihoods of its people are dependent on the climate, because a large proportion of GDP is associated with climate sensitive activities.
- Current climate variability and extreme events lead to major impacts and economic costs in Nepal. These are dominated by floods, but also include rainfall variability on agriculture (rain-fed agriculture, soil erosion, droughts) and low season river flows reducing hydro-electricity generation.
- The annual direct costs of current climate variability in Nepal, on average, are estimated to be equivalent to 1.5% to 2% of current GDP/year (approximately US$270 million to 360 million/year in 2013 prices). In extreme flood years they can be much higher, rising to 5% or more. This is high in comparison to international level.
- These estimation exclude the wider indirect and macro-economic costs of current variability and extremes. Including these additional effects could increase the estimations above by 25-100%.
- A key conclusion is that Nepal is not adequately adapted to the current climate. The country has a large existing adaptation deficit, which is a priority for early action.
- The sectoral analysis was complemented with a series of local case studies that included new field surveys. These found recent changes in the climate are already leading to impacts on local communities and also indicated differentiated impacts to women for some key risks.

Future climate change is likely to increase these costs, potentially leading to very high future economic impacts

- Future climate change has the potential to exacerbate the existing impacts of climate variability outlined above, as well as introduce new risks, though in some regions/sectors it could also lead to benefits.
- The study has assessed the potential future impacts of climate change using climate model projections and impact models. This is challenging due to Nepal's complex climate and hydrology. There are very large changes in elevation across the country and Nepal is affected by the regional climate.
- The study has used existing climate model projections for Nepal, focusing on downscaled outputs, which have high spatial resolution. Analysis of these projections shows high uncertainty associated with future climate change, with large differences found across alternative future scenarios and between different climate models. The study has considered this uncertainty in analysing impacts and adaptation responses.
- The analysis has used crop models to assess potential impacts of future climate change on the agricultural sector in Nepal. The results show a strong distributional pattern over time and across the country, with potentially high impacts in the plains (Terai) in later years, but with some potential benefits in the Hills and the Mountains.

- In the longer-term (mid-century and beyond), the study projects high overall net losses to the agricultural sector in Nepal due to climate change, which are equivalent to approximately 0.8% of current annual GDP, though in extreme years these impacts are likely to be much more severe.
- There is uncertainty around these estimates. Under some future projections they could be smaller (especially when current and planned irrigation are included) but under other projections they could be larger, especially if there are changes in variability and extremes. A number of additional potential impacts are also highlighted (though not modelled) including increased floods, soil erosion and changes in pest and disease prevalence/range.
- The analysis has also considered the potential impacts of climate change on the hydro-electricity sector in Nepal, which is a major source of future economic and export growth.
- The analysis used the climate projections in hydro-plant scheduling and power generation investment models to assess the potential impacts of climate change on electricity generation. The study considered two alterative climate model projections for this analysis.
- The first model projects lower dry season flow and lower energy availability, which increases the additional capacity required for the system to meet demand, increasing investment costs. The impacts are estimated at a total of US$2.6 billion (present value, PV) over the period from now to 2050. However, the second model projects an increase in dry season river flows, reducing investment costs, thus leading to economic benefits (of around US$0.2 billion (PV)).
- While there are potentially large impacts on this sector, the analysis highlights the uncertain nature of future effects. There is, therefore, a need to consider uncertainty in future sector planning.
- A number of other potential impacts have been identified for this sector though not modelled. This includes the risks of high flows (floods), the impacts of glacial melt rates on flows, and the risks of Glacial Lake Outburst Floods (GLOFs).
- There are also potentially large impacts from future climate change on water-induced disasters. The impacts are projected to vary significantly between catchments, leading to large differences in the results from different climate and hydrological models (even for the same catchment). However, climate change is generally projected to increase the intensity and frequency of high flows, and thus increase flood risks and impacts in Nepal.
- Model projections for two contrasting river basins suggest that climate change could increase current high flows (relative to existing levels) by 20-100% by mid-century. At the same time, the return period of a flood of a certain magnitude is found to reduce significantly, such that the flow associated with a 1-in-10 year event could happen every few years due to climate change, and the return period for a 1-in-100 year event under current conditions could reduce to once every few decades.
- An indicative analysis of the impacts of climate change on water induced disasters at the national level has been undertaken. This estimates that the additional average expected annual direct cost could be equivalent to 0.6 to 1.1% of current GDP (over and above existing damages) by mid-century, with an upper estimate of almost 3%.
- When indirect costs (such as transport and industrial disruption) and macro-economic costs are added, these costs are expected to rise further. These future impacts will also be affected by future population and asset growth (increasing impacts) but potentially reduced by higher adaptive capacity and development.

- Overall, the study concludes that there are potentially high economic costs due to future climate change in Nepal. The direct costs from the three sectors could be equivalent 2 to 3% of current GDP by mid-century (current prices, with static assumptions), though more modest or more extreme outcomes are also possible.
- While there is uncertainty associated with these estimates, it is stressed that this is not a reason for inaction, but there is a need to consider this uncertainty in planning adaptation responses.

Adaptation can reduce these impacts, but the high uncertainty necessitates an iterative approach

- Adaptation can reduce these impacts of climate change, but it has a cost. Significant resources are likely to be required to address the existing adaptation deficit, as well as to prepare for future climate change.
- To address uncertainty, the study has adopted an iterative framework for adaptation. This starts with the current adaptation deficit, and then considers the risks from future climate change.
- A number of early priorities for adaptation have been identified, which build capacity and introduce low and no-regret adaptation options to address the adaptation deficit.
- The study has also undertaken a climate risk screening and investment and financial flow analysis. This shows that the Government of Nepal is already taking actions to build resilience. However, it also identifies that a major increase in adaptation investment is needed.
- The additional adaptation investment needs up to 2030 for mainstreaming climate change in the three sectors (agriculture, hydro- and water induced disasters) have been analysed. The total additional costs for adaptation are estimated at US$2.4 billion (PV).
- Finally, the study has identified the major long-term challenges from climate change (mid-century and beyond) and identified early actions needed to address these long-term risks, as part of iterative adaptation pathways.

Recommendations and future research

- A number of priority areas for future consideration and research are proposed in the report.
- The most important ones are to build capacity and enhance research and monitoring; to scale-up early low and no-regret adaptation measures; to move towards sector adaptation investment plans (aligned to iterative pathways); and to start initial programmes for critical early steps.

Technical Summary

At the request of the Government of Nepal, the Climate and Development Knowledge Network (CDKN) has funded this study on the 'Economic Impact Assessment of Climate Change in Key Sectors in Nepal'. The work has been led by Integrated Development Society (IDS), Nepal, working with Practical Action Consulting Limited, Nepal and Global Climate Adaptation Partnership (GCAP) in the UK. The primary objectives ofthe study are:

(i) To provide headline and sectoral estimates of the impacts and economic costs of climate change for a number of key risks in Nepal; and

(ii) To assess climate compatible development adaptation options to address these potential impacts.

The study mainly focuses on the climate change impact on productivity of major cereal crops, hydropower generation and water-induced disasters. This report is the technical report of the study. A summary report and summary brief in Nepali and English version are also available.

Country and sector context

The study first undertook a country and context analysis, to identify the key issues for the agricultural sector, hydro-electricity sector and water-induced disasters, and confirmed the selection of these sectors as the focus for research in the study.

The agricultural sector accounts for approximately three-quarters of employment and one-third of GDP in Nepal. Agriculture is predominantly small-scale farming and much of this is dependent on natural rainfall, although there is a growing level of irrigation.

Water is critical for Nepal's power production as hydro-electric plants provide around 90% of total electricity. Rainfall has a major influence on electricity generation, affecting run-of-river plants (i.e. those without storage reservoirs), as well as reservoir levels. During the dry season, river flows are insufficient to operate all plants, which leads to planned electricity interruptions, compounding existing problems of unmet demand.

Nepal is also frequently affected by water-induced disasters. Flood inundation is a major climate-related hazard in the country, affecting property, agriculture, infrastructure (roads, bridges, communications and transmission networks), business and commerce, and causing loss of human life. Landslides, which are often related to extreme rainfall or flood events, can also have significant impact on communities and infrastructure. Floods are particularly associated with summer monsoon rains and are a constant feature of current climate variability. There are also additional risks from Glacial Lakes Outburst Floods (GLOFs), which can impact communities and infrastructure for considerable distance downstream.

In summary, a large proportion of the GDP in Nepal and the livelihoods of its people are associated with climate-sensitive activities.

Furthermore, Nepal already experiences high impacts from current climate variability, and future climate change has the potential to exacerbate all of these risks, as well as introduce new ones. The study has undertaken a detailed assessment of the potential impacts of climate change and the associated economic costs in these sectors, as well as studied potential adaptation responses.

Methodology

The recent climate change literature on vulnerability, impacts and adaptation has adopted a new framework, highlighting the need to focus on early time periods and consider uncertainty. The method in this study recognises this shift and has developed an analytical framework that starts with current climate variability, and then assesses future climate change, taking account of uncertainty. It uses an iterative adaptive management framework, as highlighted in recent IPCC reports (2012). At the same time, recent studies have recognised that analysis of climate risks and adaptation responses needs to be assessed against the context of national development objectives and sectoral plans, and needs to consider socio-institutional issues as well as technical options. This leads to the analysis of impacts and adaptation responses as a dynamic and evolving process, requiring different types of activities over time.

It is not, however, possible to address all of these issues - across all time periods - using a single analytical method or model. A comprehensive coverage can be achieved by combining various lines of evidence and different methodological assessments. This study has developed a methodological framework that does this, by breaking the analysis into a series of building blocks (work-streams) that collate the following evidence base:

- **Work-stream 1 assesses the costs of current climate variability** in Nepal in the agricultural, hydro-electricity and water-induced disaster sectors, using risk assessment methods. For adaptation, it focuses on addressing short-term climate variability by building capacity and "no and low regret" options (i.e. options which make economic sense whether or not future climate change occurs).
- **Work-stream 2 looks at the risks to current development policies** over the short-medium term in Nepal (to 2030), building a current and future investment and financial flow analysis and estimating the potential costs of adaptation to mainstream resilience.
- **Work-stream 3 looks at the longer term impacts and economic costs of climate change** in Nepal (i.e. for around 2050) using scenario-based impact assessment with climate projections and impact models. For adaptation, the focus has been on identifying the early actions required (in the short-term, i.e. the next decade) to plan for the longer-term challenges identified, taking into account the high uncertainty.

The information from these three work streams is brought together to assess the overall impact and economic cost of climate change in Nepal over time, and to develop an iterative adaptation pathway.

In implementing the method above, the study engaged and consulted with a wide range of stakeholders. The project reported to a Government Steering Committee, which met at key points during the study. This ensured enhanced capacity, joint ownership of the project outputs, and confirmed the integrity of the national context. Furthermore, a series of stakeholder events and workshops were held with a diverse group of stakeholders. These were complemented with technical working group meetings at key points during the project. Regarding capacity building of local researchers, practitioners and government officials, it was ensured that all tasks were undertaken by local and international teams working together, and a series of training and information-sharing activities were held for local researchers and government officials. Finally, the project undertook a needs assessment in the Government of Nepal, and on the basis of this, designed and held a major 3-day training session with Government officials. The training was presented by Nepali and international experts, with the aim of building the capacity of government officials and key stakeholders on the methodology and approaches for assessing the economic impacts of climate change, as well as to information on how this information can be used for adaptation strategies and wider planning.

Work-Stream 1. The impacts and economic costs of current climate variability

The first work-stream has assessed the current climate of Nepal and the impacts and economic costs of existing climate variability. Nepal has an extremely varied and complex climate, driven by the contrasting terrain and regional weather systems. Within a few hundred kilometres, the elevation rises from the flat Terai plains - with a low point of 70 metres above sea level - to the top of Mount Everest (8,848 metres). This drives strong temperature gradients across the country. Nepal also experiences complex seasonal weather patterns, which are heavily influenced by the Himalayas and the annual monsoon.

Analysis of recent observational data shows that the climate of Nepal is already changing. Temperatures have increased strongly over recent decades, rising at a much faster rate than the global average. There have also been changes in precipitation, including heavy rainfall extremes, though the trend is more complex and there are wide variations across the seasons and the regions of the country. Changes in Nepalese glaciers have also been observed, with some of these retreating and thinning. The complex climate of Nepal leads to high levels of current climate variability and frequent extreme events.

Water-induced disasters associated with the monsoon rains, notably floods in the plains and landslides in the hills, are frequent in Nepal and lead to loss of life and significant damages. The direct damage of these events are large. The study has assessed the historical information over the last thirty years (the period for which data are available), and estimated the economic cost of these events, including the health and welfare-related impacts. This has revealed that the total annual economic cost of water-induced disasters is equivalent to 1.5% of GDP (approximately US$270 million in 2013 prices). There is, however, wide variability across years; for example, the economic cost of the major floods in 1992 was over 80 times higher than the lowest years. In exceptional years, the economic cost of floods was estimated to be equivalent to 5% of current GDP.

Importantly, the results only consider the direct economic costs of these events. They do not include the costs to natural ecosystems (and ecosystem services), and the indirect effects and overall macro-economic costs. Indirect costs occur as a consequence of flood impacts and damages (e.g. business disruption and lost wages). Macroeconomic impacts include the aggregate impacts on economic variables such as GDP, consumption and inflation due to the effects of disasters, as well as the shift of government resources towards relief and reconstruction. Assessing these additional impacts requires linked models, such as input-output catastrophe models, studying the effects of shocks in Compute General Equilibrium (CGE) models, or otherwise post-assessment of major disasters. While it has not been possible to model these impacts in this study, comparison of similar events in other countries indicates that the total cost of water-induced disasters (when indirect and macro-economic costs are included) are 25% to 100% greater than the direct costs alone.

There are also natural hazards in Nepal in the form of Glacial Lake Outburst Floods (GLOFs). While the damage and loss of life from these events are locally damaging, they are often low in terms of fatalities and damage costs when compared to national flood damages reported above. This is due to the low frequency of

GLOF occurrence (there have been seven major GLOFs over the past fifty years) and also because they affect a more limited geographical extent.

Nepalese agriculture is predominantly small-scale farming, which is heavily dependent on natural rainfall. Rainfall and other climatic factors are critical for crop yields, resulting inlarge annual variations in production. The sector is also affected by climate extremes, including droughts as well as floods, and other weather extremes, such as hailstorms. The economic cost of major droughts, such as experienced in 2006 and 2009, are large. The direct economic cost of these events (from lost agricultural output) has been estimated at 2.0% and 0.4% of current GDP in 2006 and 2009, respectively. The full economic cost of these events would be even higher, due to the health and welfare losses associated with food insecurity, wider disruption and the macro-economic effects. Nepalese agriculture in the hills and mountains is also affected by soil erosion, due to the steep gradients and intense monsoon rainfall, which reduces soil fertility and agricultural productivity.

Current climate variability also affects hydro-electricity generation. The seasonal variation in rainfall means that a number of run-of-river hydro plants do not operate at the planned or optimum capacity during the driest months of the year (January, February, March and April). This leads to planned rolling blackouts (intentionally engineered supply interruptions) to consumers, which is often referred to as 'load shedding' in Nepal. These power interruptions have a high economic impact. These impacts are greatest in low rainfall years, where it can also reduce the storage reservoir recharge (which occurs during the monsoon). An analysis of the impact of climate variability on electricity production (and the impact of planned interruptions) indicates that economic costs could be equivalent to 0.1% of GDP per year on average, and 0.3% in very dry years. Hydro-electric plants are also subject to the risks of floods including, for some, the risk of Glacial Lake Outburst Floods (GLOFs). There was the loss of a multi-million dollar hydro-power facility in 1985 due to a GLOF event, and more recent losses of micro-hydro plants from floods have also been recorded.

The analysis above shows that the direct economic cost of current climate variability in Nepal is very high. These impacts significantly affect the livelihoods of hundreds of thousands of people in extreme years. They also have high economic costs, estimated at 1.5% to 2% of current GDP equivalent as an annual average (approximately US$270 million to 360 million/year in 2013 prices), and as high as 5% for extreme years. The damages in Nepal are dominated by water-induced disasters, though major drought years are also significant. When indirect and macro-economic costs are added, the total costs are likely to be 25% to 100% higher than the direct costs alone.

These results compare to average disaster losses (from natural disasters) of around 0.3% of GDP for low-income countries and 1% for middle-income countries (IPCC, 2012), thus showing the impacts of current climate variability and natural disasters in Nepal are high by international levels, and are similar in scale to the most affected countries globally.

A key conclusion is that Nepal has a high existing adaptation deficit, defined as the failure to adapt adequately to existing climate risks, which requires urgent action. Addressing this deficit is an early priority; otherwise adaptation to future climate change will be less effective. Addressing the current deficit will also lead to immediate economic benefits and is thus a priority for early low-and no-regret adaptation.

The analysis also shows a high level of spatial variation regarding impacts across the country, reflecting differences in climatic and agro-ecological zones. There are also large differences in the distribution of impacts across groups in society (by gender or income level). Three local case studies were undertaken to investigate these issues and complement the national-level focus above. These case studies undertook new fieldwork and surveys and were also explored through community-based perceptions.

The first case study investigated hailstorms, as an additional impact of climate variability. During the data collection phase, a household survey was conducted in Kaski District, which is particularly affected by these events. The survey recorded high impacts of hailstorms on crop production, livestock rearing and infrastructure from these events. It also observed a strong community perception (80% of people surveyed) that these events have been increasing in frequency and intensity.

The second case study investigated flooding in the West Rapti River basin, one of the most flood-prone areas of Nepal, focusing on Banke District. This case study investigated the impacts of floods on livelihoods and found high impacts in major flood years, as well as increased occurrence of water-borne diseases. The study also found strong distributional differences across the affected communities, with the highest impacts on children and poor females.

The final case study focused on the effects of climate variability and recent trends on buckwheat farming in Mustang, a semi-arid part of the mountainous agro-ecological region of Nepal. This is an area with high vulnerability and that has also experienced high rates of warming in recent decades. The household survey reported a reduced production of buckwheat (a major crop in the area) in recent years, as well as a community perception of increasing rainfall intensity and flood events.

Future climate change projections

Toassess the future impacts of climate change (in work-streams 2 and 3), climate model projections are needed. However, the modelling of climate change in Nepal is extremely challenging. This is due to the large differences in elevation and the complex regional climate. All future projections have a high degree of uncertainty and the analysis of impacts and adaptation needs to take this into account.

As part of the study, existing climate model projections for Nepal were used as an input for the impact models. The study focused on downscaled regional climate model runs, because global climate models do not provide the necessary level of spatial resolution required. However, only a small number of these regional climate model runs exist for Nepal. Ideally, all of these should have been used to provide an inter-model comparison, but due to differences in time period, data resolution and bias correction, only the Indian Institute of Tropical Meteorology model runs were suitable for the study. This projection provides data for the A1B scenario - a medium-high emission scenario that does not consider global mitigation.

The regional climate model run for this A1B scenario projects a strong increase in temperature across the country, with average maximum and minimum temperatures increasing by 3° to 5°C by the end of the century (across seasons and areas) relative to the baseline period. The changes in precipitation are more varied, with high spatial and temporal differences. Depending on the future time period and the region, increases or decreases in precipitation are projected, thought here are indications of increasing extreme precipitation.

As this data set is only for one regional climate model for one socio-economic scenario, a comparison was made to other projections, including statistically downscaled projections (which downscale global model results with local meteorological observations), to consider uncertainty. The analysis found a consistent warming trend across all of the projections, but with variations depending on the scenario and the model. However, the analysis found very large differences in projected rainfall, even in the sign of change (i.e. an increase or decrease from current), with large variations across seasons and locations. This uncertainty was also present for extremes such as heavy precipitation. To explore this, additional data from a second parent Global Climate Model run was used for selected basins for water sector impacts.

These uncertainties are compounded by the effects of temperature and precipitation on the levels of glacial ice reserves and melt-water. A number of studies report that this may increase short-to medium-term water availability due to higher melting with rising temperatures, but then lead to a decrease in the longer-term, at least for some river basins, though there is considerable uncertainty.

The review findings reinforce the need to work with multiple model projections and inter-model comparison data in Nepal, and cautions against the use of central projections for optimised responses. A direct implication is the need to recognise this uncertainty in planning adaptation response, and in the design of iterative strategies, noting that this uncertainty is not a reason for inaction.

Alongside the future projections of climate, the study also considered strong socio-economic changes in Nepal. These are likely to be as important as future climate change signals in the sectors considered, and there is a need to link the two together when considering climate change and adaptation responses. These signals can act positively as well as negatively in terms of future risks. For example:

- A major risk factor - especially for future water-induced disasters - is the high population growth in Nepal. Future projections indicate an increase in population from the current 30 million to around 35 million by 2020, 40 million by 2030, and 46 million by 2050. This growth will increase demand forland-use, natural resources and water, and it will also increase the number of people at risk.
- Nepal is also experiencing high GDP growth, and there are high projected increases in average annual GDP growth in the future, which is projected to increase by as much as five times by 2030 (Nepal Development Vision 2030). While this will increase the assets at risk, economic development should build adaptive capacity and help reduce vulnerability.
- There are also strong sectoral trends, which are significant in looking at future climate change. These include strong growth in hydro-electricity, including for power export, and growth in agricultural productivity.

Work-stream 2. Analysis of Existing Policy and Plans and Climate Risks

Work-stream 2 looks at the risks from climate change to current development policies over the short to medium term in Nepal. This work-stream places the analysis of impacts and adaptation within the institutional structure of the Government of Nepal, and takes account of the existing programmes and policies in place. It also provides the baseline information to assess future mainstreaming needs and adaptation investment for the medium term, aligning it with the existing country development plans.

The study has first undertaken an investment and financial flow analysis, a form of Public Financial Management (PFM) assessment. It looks at the current and future (planned) investment in each of the three sectors of interest. This analyses the activities within the current baseline of 'on-budget' programmes and activities and 'off-budget' activities funded by donors, the private sector, etc. This has been undertaken for hydro-electricity, water-induced disasters, and agriculture (including agricultural development and irrigation) sectors. The analysis finds that current investment in these sectors totals around US$1.8 billion/year[1], but is dominated by agriculture.

A future profile of baseline investment up to 2030 was then built up for each sector. For hydro-power, total investment (including public sector, off budget and private sector) was projected to increase in real terms from US$390 million/year currently to US$1.1 billion/year by 2030, with a total investment of US$5 billion for the period 2014-2030 (discounted). For irrigation, investment is projected to increase from US$1.4 billiion/year currently to US$3.8 billion/year by 2030, with a total present value investment of US$17 billion for the period 2014-2030 (discounted). Finally, for activities to address water-induced disasters, investment is projected to increase from US$29 million/year currently (on river management, watershed conservation) to US$60 million/year by 2030, with a total present value investment of US$321 million for the period 2014-2030 (discounted). This shows continued high investment and growth in agriculture. It also shows a much higher increase in hydropower investment. The planned investment in water-induced disasters is lower, reflecting the dominance of state and development assistance funding (for a public good).

The analysis has reviewed the existing policies and plans in place to assess the risks of climate change in these areas and whether climate resilience is already being mainstreamed (i.e. to see if the investment profiles above need additional adaptation investment). The aim of this climate risk screening was to assess the level of 'climate readiness' of the current policy framework and to identify opportunities for mainstreaming.

A key finding is that the Government of Nepal is already mainstreaming climate change considerations into its national level planning frameworks such as the Three Year Plan, and has developed a strong package of supporting climate change strategies (e.g. NAPA, LAPA, and the Climate Change Policy). However, at a sector level there is less mainstreaming, with objectives and actions often not framed in the context of climate change. More recently, a number of strategy documents have been produced that do explicitly consider and address climate change impacts. Progress has been particularly strong in the agricultural sector, where the Priority Framework for Action, and the draft Agricultural Development Strategy, both put climate resilience at their core. In other sectors (hydro-power and water-induced disasters), less progress has been made in updating policy to fully reflect current, and especially future, risks. However, many of the policies and programmes relevant to the water sector implicitly promote activities that support resilience, and this offers a solid basis for the reframing of the existing legislation going forward. The analysis also identifies priority areas for strengthening and recognising climate considerations in future adaptation mainstreaming.

The study has also considered the recent analysis of the level of resilience mainstreaming in the GoN budget. This identified approximately NRs. 7 billion of activities as 'reducing the negative impacts of climate change', primarily in the water-induced disaster and agricultural development programmes. This also identified gaps in mainstreaming priorities, which have been taken forward for further analysis of future adaptation needs.

[1] Unless otherwise stated, monetary values in this report are given in dollars at 2013 prices and exchange rates.

Work-stream 3. Future Impacts and Economic Costs of Climate Change

The final work stream assesses the future impacts of climate change, using scenario-based impact assessments with downscaled climate model projections and sector models.

The analysis of the impacts of future climate change on the agricultural sector has focused on the key crops grown in Nepal: maize, wheat and rice, using the Decision Support System for Agrotechnology Transfer (DSSAT) crop model. Overall, the results show a strongly differentiated pattern over time and across the country. It finds potentially high impacts from climate change in the Terai in later years (after 2050) especially for rice and wheat production. It also finds a varied pattern in the Hills and Mountains, including some potentially high benefits, but sometimes also adverse impacts. The study also finds higher climate variability in some regions in the long-term, which would increase year-to-year variability in production. The study has then valued these changes to provide analysis of the overall change in total production.

The overall finding is that in the 2030s, there is an estimated net increase in production with economic benefits, but by 2070, there is an estimated decrease in most crops with high net economic impacts, that latter estimated at US$140 million/year (undiscounted), equivalent to approximately 0.8% of current annual GDP. In extreme years the effects of climate change will, however, be much more severe. This includes direct costs only; the total cost (including indirect and macro-economic costs) would be higher, especially for extreme years. The study has also considered the climate model uncertainty: the large difference projected in key variables (annual and season rainfall and variability) between different models translates into a wide range of possible impacts on the agricultural sector. The range of results includes more modest or even positive outcomes (e.g. when average rainfall increases) but also possible futures with much more severe impacts associated with large seasonal reductions or greater variability. This uncertainty is exacerbated by other potential impacts on the sector, including the impacts of increased flooding, increased soil erosion and the changing range and prevalence of pests and diseases.

The analysis of the future impacts of climate change on hydro-electric power was assessed using hydrological models (to link climate outputs with changes in river flows), which provided inputs to a hydro-electricity optimisation modelling system (comprising the VALORAGUA and Wien Automatic System Planning model (WASP) models). These models assessed the impacts of projected changes in river flows on hydro-electricity plants, as well as overall electricity system planning. The analysis considered changes from climate change on dry season flows and the operation of run-of-river plants, as well as the effects of rainfall and river flows on reservoir storage recharge. The results were used to consider the effects of climate change on electricity generation, and thus, on the future plant investment profiles needed to meet future electricity demand in Nepal. However, the analysis of river flows with climate change is very challenging, due to the complex nature of Nepal's climate, the uncertainty in rainfall projected by the climate models and its translation into daily river flows, and the additional uncertainty from glacial melt water. The study found large differences projected by different climate model results and thus the analysis compared two different climate models.

The first model projected lower dry season flows and lower energy availability. The additional capacity needed to meet future demand under this scenario led to additional generation capacity of 2800MW (by 2050) and generation expansion costs of US$2.6 billion (PV) for the period up to 2050, relative to the baseline (i.e. an impact from climate change). This could also lead to increasing numbers of thermal plants, increasing greenhouse gas emissions. However, the second model, which projects higher river flows in the dry and wet seasons leads to increased energy availability and avoids the need for additional plants, thus leading to a reduction of generation expansion costs of - US$170 million (present value) over the period up to 2050 as compared to the baseline.There are also additional risks from increases in high flows and GLOFs, which could lead to additional impacts. The overall results indicate that the potential importance of climate change on the sector is high. However, there is considerable uncertainty over future changes, which vary by river catchment and over time, with additional uncertainty from the effects of climate change on glacial melt water on river flows. It is highlighted that using historic data for the design of plants will not capture these possible future changes. This uncertainty necessitates more monitoring and research, and a move to more flexible and iterative planning.

Finally, the hydrological data for two river catchments (the Tamor and Bagmati rivers) was used to assess the potential future impacts of climate change on water-induced disasters. The hydrological model results were analysed to look at two inter-related questions. First, to look at the change in the frequency of current return periods (i.e. for a high flow event that happens 1 in every 10 years now, as a historical average), what will be the future return period for that same flow with climate change, and how much more frequently will such an event occur? Second, how much will the magnitude of a given high flow increase by, i.e. how much bigger will the 1 in 10 year flow event under climate change be, and by how much might this increase damages? To do this, the analysis looked at the change in the frequency and intensity of high river flows, and thus the risk and impacts of flooding (i.e. the shift in the probability-loss relationship).

The increase varies with the river catchment, climate, and hydrological model; but in one example, the increase in current high flow (intensity) was found to increase by 20-100% by mid-century (2040s) with climate change. At the same time, the return period for a 1-in-10 year events was found to reduce to 1-in-5 years (or less) and the risks of very major events, such as a 1-in-100 year event, were found to reduce to once every 10-30 years with climate change.

An analysis of the potential economic impact of climate change on water-induced disasters at the national level was undertaken, using the hydrological modelling results, and building on the analysis of historical damages. The analysis indicates the direct economic costs of climate change (in addition to baseline variability) at a central range of US$100 million to US$200 million/year by mid-century (equivalent annual damage, current prices, undiscounted), equivalent to 0.6 to 1.1% of current GDP. The total costs (including indirect and macro-economic costs) would likely be 25 to 100% higher. However, the upper value is much larger, with an upper estimate of almost 3%/year of current GDP equivalent.

These are based on static assumptions (i.e. current population and development levels). The high population growth in Nepal will potentially increase impacts, as the population is projected to increase by a third by 2030 and by 50% by 2050. Rising GDP (and per capita GDP) is even higher. This has the potential to increase assets at risk. However, rising wealth could increase adaptive capacity and should result in more autonomous and planned adaptation (to existing risks). Future impacts will therefore depend on whether future risks are planned for in development planning and land-use policy.

The increased incidence of flooding is also likely to have an impact on hydro-electricity plan as it increases sediment transport and results in a higher proportion of downtime for plant maintenance. Glacier retreat, attributed to rising temperatures at higher elevations, is also considered likely to affect the flow regimes of rivers and increase the risks from Glacial Lakes Outburst Floods (GLOF).

The overall results show differences between the three major sectors considered. The impacts of climate change on the agricultural sector are potentially large, excluding autonomous and planned adaptation. However, the results are highly sensitive to future climate projections. For hydro-electricity generation, the impacts of climate change on river flows are likely to be highly significant, but there is high uncertainty on the exact changes and whether positive or negative impacts will occur on generation levels. Finally, for water-induced disaster for the catchments studied, there are negative impacts from climate change, with increases in high flows and reductions in return period, although again the level of change varies across models. The results indicate that the impacts of climate change on water-induced disaster could result in the highest costs of the sectors considered.

Finally, the study has looked at the wider economic costs due to climate change. An analysis of input-output tables for Nepal has identified the main linkages (across different economic sectors) and their relative climate risks. These show potentially important linkages that would increase the impacts above. They also indicate high potential impacts for parts of the economy that rely on agricultural and livestock-based inputs or water-intensive processes.

Overall, the study concludes there that are potentially high economic costs from climate change in Nepal. The direct costs from the three sectors could be equivalent 2 to 3%/year of current GDP by mid-century (static assumptions). While there is uncertainty associated with these estimates, it is stressed that this is not a reason for inaction, though this uncertainty does require consideration in planning adaptation responses.

Adaptation

The study has assessed the potential adaptation options to respond to the current and future risks identified in the agricultural, hydro-electricity and water-induced disaster sectors in Nepal. An initial review identified a very large number of potential options, totalling several hundred options. The study prioritised indicative options by building an iterative adaptation pathway that starts with current climate variability and looks at future risks of climate change (including uncertainty) and looking for synergies with climate-compatible growth.

The analysis has identified potential options in each of the three work-streams: in addressing the current adaptation deficit, in mainstreaming adaptation into development plans, and in early action to address long-term challenges.

Work-stream 1 focused on adaptation options that address the current adaptation deficit, with the identification of capacity building (i.e. data and information, awareness raising, institutional strengthening, research, etc.) and low-and no-regret adaptation options. In the agricultural sector, these centre on enhanced agro-meteorological information and forecasting, capacity building, and sustainable agriculture/climate-smart agriculture (e.g. soil and water management, conservation agriculture, agro-forestry, soil conservation and slope stabilisation, rainwater harvesting). In the hydro sector, these are primarily based on improved management and retrofitting of older equipment in current plants, but also looking at efficiency (e.g. transmission loss reduction, end-use energy efficiency). In the water induced disaster area, these centre on enhanced hydrological monitoring and forecasting, enhanced early warning systems, capacity building and governance, community based adaptation and people centred interventions, and ecosystem based adaptation.

It is noted that many of these early options are already included in existing policies and programmes, or have been trialled. The priority is therefore for scaling-up and also the introduction of enhanced techniques (i.e. ensuring good practice). This requires supporting capacity building (information, awareness raising and education, monitoring, institutional strengthening, research and pilots). It is also highlighted that there are some barriers to the introduction or uptake of many of these early options, including opportunity or policy costs, and they are unlikely to happen autonomously. There will therefore be a need to provide the necessary enabling environment (support, policy incentives, etc.) and planned support.

Work-stream 2 has built an adaptation investment and financial flow analysis scenario, assessing the additional investment needed to mainstream climate in existing investment profiles. The baseline investment profiles have been adjusted to include adaptation in each of the three sectors, based on discussions and the analysis of the impact information across the study. This has built up adaptation investment plans to 2030, considering public and private budget increases.

The total additional adaptation needs are estimated at a total over the period of US$2.4 billion (present value, discounted), an increase of approximately 10% over and above the investment baseline.

A sensitivity analysis has also been undertaken to capture the uncertainty over the future climate risks. Under the high impacts scenario, the estimated additional investment requirements would need to increase more quickly. Importantly, the decision on which pathway to adopt should be based on the data and learning over the next few years.

Work-stream 3 looks at the major potential risks of climate change to Nepal in the longer-term, but noting the high uncertainty, it identifies iterative adaptation pathways, which allow a flexible approach, rather than selecting a specific option now that may or may not be needed. For agriculture, a key issue is building the response capability to respond to increased risks and potential opportunities, with enhanced monitoring/research and pilot testing to develop capability. Given the likely response for increased irrigation (especially in the Terai), there is also an early priority for integrated water resource management. For hydro-electricity, a clear priority (already recognised) is for enhanced monitoring and research, including for GLOF risks. In the short-term, there is a need for enhanced risk screening to take account of climate in design. Under some future scenarios, diversification strategies might be needed (with more small-scale schemes), but given the higher costs of these, transmission and end-use energy efficiency is recommended to buy more time. For water-induced disasters, enhanced early monitoring and research is again highlighted to help provide information and reduce uncertainties, with the use of this information in risk screening for integrated (sustainable) land use-planning, noting this requires early institutional strengthening. There is also a need for future flood defence infrastructure to be designed with flexibility to future possible changes in mind, and the development of non-technical management programmes as an alternative: early work to start to analyse options and develop the institutional basis for these is a priority.

Discussion, Recommendations and Policy/Research Priorities

A number of priority areas for future consideration and research are set out in the report.

In terms of research, there are priorities for work to better understand climate and impact uncertainty. This includes improved climate modelling (downscaled results) and a greater focus on multi-model ensembles. It also includes consideration of improved climate and hydrological data (monitoring) and improved hydrological models applicable at different scales. There is also a need for advanced analysis of the indirect economic costs of impacts.

In terms of the linkages to policy, the most important priorities are to scale-up existing resilience to address the current adaptation deficit (including a focus on low and no-regret options), to move towards sector adaptation investment plans (aligned to iterative pathways, including assessment of costs and benefits and the mainstreaming into existing plans), and to start early programmes for critical early steps to address potential major future risks.

It is stressed that this assessment only covers a number of sectors and there is a need to extend these types of analysis to include cross-sectoral assessment (e.g. wider water management) and into other sectors (e.g. health, tourism).

Finally, to support all of these areas, there is an urgent need to build capacity, with information and awareness raising, monitoring, research, and institutional strengthening.

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1 Introduction

1.1. Background, Objectives

At the request of the Government of Nepal, the Climate and Development Knowledge Network (CDKN) has funded this study on the 'Economic Impact Assessment of Climate Change in Key Sectors in Nepal'. The study mainly focuses on the climate change impact on productivity of major cereal crops, hydropower generation and water-induced disasters. The work was led by Integrated Development Society (IDS), Nepal, in collaboration with Practical Action Consulting Limited, Nepal and the Global Climate Adaptation Partnership (GCAP) in the UK.

The study had two main objectives:

- First, to provide headline and sectoral estimates of the impacts and economic costs of climate change for key sectors, which were identified as the agricultural sector, hydro power generation sector and water-induced disasters, to provide input for the Government's assessment of losses and benefits from climate change in various geographical areas and development sectors by 2013.
- Second, to provide information on climate-compatible development options in these sectors, so as to address these risks and help the Government strategically start to consider options for climate-compatible development pathways.

The project has aimed to be comprehensive, participatory, and country-oriented. The project has aimed to achieve a high level of interaction and co-production between the research team and key Government stakeholders. To achieve this, the project undertook extensive stakeholder engagement and consultation. It worked directly with key Government and wider stakeholders to address the key challenges and issues, with discussions during each phase of the project to ensure that stakeholders had the opportunity to discuss the work-plan, and the results. National workshops on the project were also organised at the beginning and end of the inception phase, and at the end of the implementation phase, to seek inputs from a wide group of stakeholders.

The project has also aimed to build capacity in-country (with Government, stakeholders and researchers), and a capacity building plan was developed and implemented. Consistent with this plan, tasks were undertaken collaboratively by local and international teams. Further, a government needs assessment survey was carried out, and using the results, a major climate change training workshop for Government officials was designed and delivered in Kathmandu in January 2013.

1.2. Outline of the Report

This report provides a summary of the technical work. The report isset out as follows:

Chapter 2	provides the baseline context.
Chapter 3	outlines the method developed and applied in the study.
Chapter 4	assesses the impacts of climate variability in Nepal and reports on the field case studies.
Chapter 5	summarises the projections of future climate change in Nepal.
Chapter 6	assesses the risks to short-term plans and presents the investment financial flow analysis.
Chapter 7	presents the results of the impact assessments in key sectors.
Chapter 8	reports on the adaptation assessment and the possible responses to the risks identified.
Chapter 9	presents the policy/research priorities from the project.

This report is the technical report of the study. A summary report and summary brief are also available.

2 Country and Sector Context

Key Summary Points:

- The study first undertook a country and context analysis to identify the key issues for the agricultural sector, hydro-electricity and water-induced disasters.
- A key finding is that a large proportion of the GDP in Nepal and the livelihoods of its people are associated with climate sensitive activities.
- The agricultural sector accounts for around three-quarters of employment and around one-third of GDP. Agriculture is predominantly small-scale farming, and much of this is dependent on natural rainfall, though there is an increasing level of irrigation. Historically, the agricultural sector has been heavily affected by floods and by erratic rainfall, although there have also been droughts in recent years.
- Water is critical for Nepal's power production, as hydroelectric plants provide around 90% of total electricity. Rainfall has a major influence on generation, affecting run-of-river plant (i.e. those without storage reservoirs) as well as reservoir levels. During the dry season, river flows are insufficient to operate all plants, which leads to planned electricity interruptions, compounding existing problems of unmet demand. Current planned outages have high costs to Nepal's industrial production and GDP. In the short term, the interruptions are projected to continue during the dry season.
- Nepal is also frequently affected by water-induced disasters. Flood inundation is a major climate-related hazard in the country, affecting property, agriculture, infrastructure (roads, bridges, communications and transmission networks), business and commerce, and, at worst, causing loss of life. Landslides, which are often related to extreme rainfall or flood events, can also have significant impact on communities and infrastructure. Floods are particularly associated with summer monsoon rains, and are a feature of current climate variability. There are also additional risks from Glacial Lakes Outburst Floods (GLOFs), which can impact communities and infrastructure for considerable distances downstream.
- The contextual analysis shows that Nepal already experiences high impacts from current climate variability, and future climate change has the potential to exacerbate these risks as well as introduce new ones. The study has, therefore, undertaken a detailed assessment of the potential impacts of climate change and the associated economic costs in these sectors, and looked at potential adaptation responses.

2.1. Introduction

The starting point for the study was to understand the country and sector context. The aim was to identify the key issues for the agricultural sector, hydro-electricity and water-induced disasters, in relation to current climate variability and future climate change, to allow the study to focus on priority areas.

2.2. The Agricultural Sector

Nepal's economy is largely based on the agricultural sector. It accounts for around one-third of GDP (see Figure 2.1), provides employment to approximately two-thirds of the active population, and represents 13% of total foreign trade (CBS, 2012). Agriculture, including livestock, is the main source of livelihood for about three-quarters of the population. The majority (>50%) of farmers are smallholders cultivating less than 0.5 ha (CBS, 2011). Further more, in addition to primary agriculture, industrial activity mainly involves the processing of agricultural products, including pulses, jute, sugarcane, tobacco, and grain.

GoN (2013) reports per Capita GDP at US$717/per person (2012/13[2]). Economic growth over the last decade has been (on average) around 4% per annum, with lower rates in the agricultural and industry sectors (around 3%), but higher growth in services (5%).

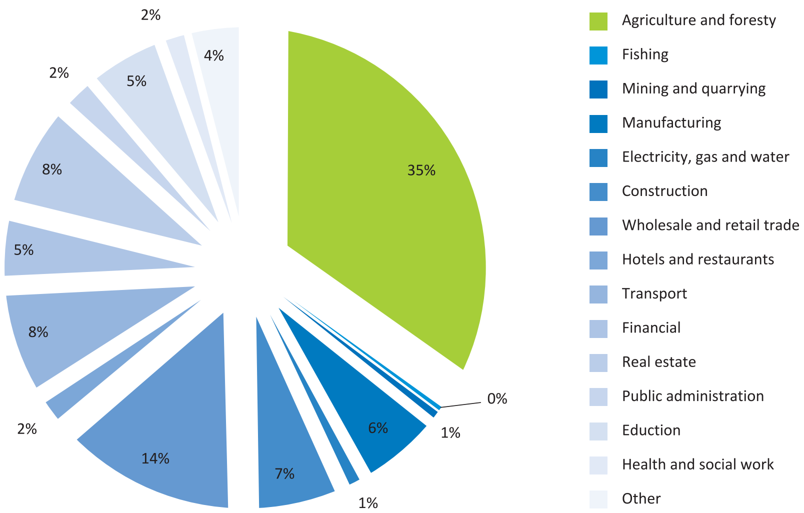


Figure 2.1. GDP Split 2011/2012

Source: Central Bureau Statistics, 2012.

Rice, maize, wheat, millet and barley are the major cereal crops grown in Nepal. The main production is shown in Table 2.1 below. Note that these values vary from year to year-primarily due to climate. As an example, production in 2012/13 was slightly lower than the previous year, as a result of lower and uneven distribution of rainfall across the country (MoF, 2012). Floods also have a major impact on production.

[2] CIA (2013) reports GDP (2012 estimated) is US$19.42 billion (official exchange rate)/$41.22 billion (purchasing power parity). The population is 30,430,267 and thus per capita GDP is around $640 per person (OER)/$1300 per person (Purchasing Power Parity, PPP).

Table 2.1. Agricultural Production – Main Production (2012/13)

Crop	Area (Ha)	Production (MT)	Productivity Kg/Ha	Crop	Area (Ha)	Production (MT)	Productivity Kg/Ha
Food crops				**Cash crops**			
Rice	1420570	4504503	3171	Pulses	333437	356743	10701
Maize	849635	1999010	2353	Sugarcane	64484	2930000	45438
Wheat	759844	1882220	2477	Tobacco	1801	2430	1350
Millet	274350	305588	1114	Jute	11301	15500	1372
Barley	28989	36973	1275				
Buckwheat	10681	10056	942				
				Spice crops			
Cash crops				Ginger	19050	228501	11995
Oilseeds	215600	179000	830	Garlic	7147	57022	7980
Potatoes	188012	2753390	14645	Turmeric	5142	49649	9657
Vegetables	246175	3409722	13851	Chilly	7220	31252	4329
Fruits	103734	1086852	10477	Cardamom	13129	7000	533

Source: MoF (2013), based on MoAD.

There are large differences in agricultural production and crops across the country, as Nepal is highly heterogeneous in terms of elevation, climate, water catchments, and agro-ecological zones (Figure 2.2)[3].

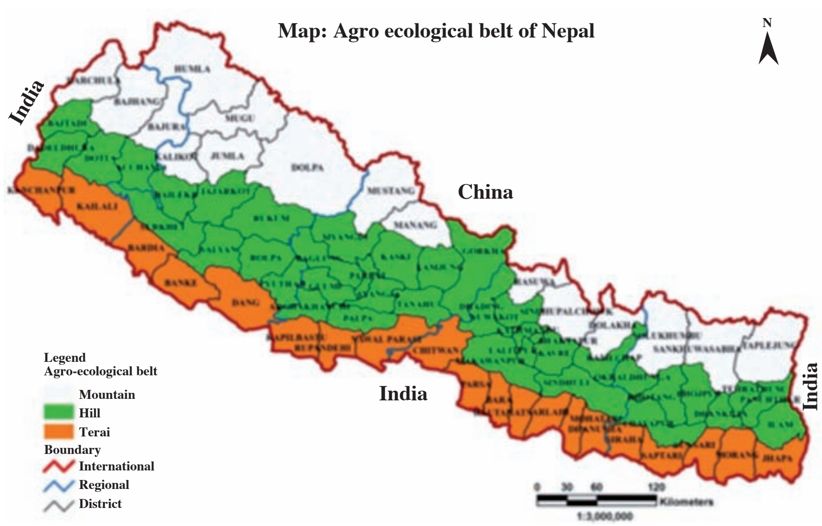


Figure 2.2. Agro-ecological Belts of Nepal

Source: MoA.

Administratively, Nepal is divided into 5 developmental regions, 14 zones and 75 districts with three major ecological belts: the Terai, Hills and Mountains (Source, MoA). However, the five physiographic regions (Terai, Siwalik, Middle Mountains, High Mountains-consisting of the main Himalayas and the inner Himalayan valleys,

[3] An AEZ is a homogenous area in terms of bio-physical conditions, including climate, terrain, soil, vegetation and fauna. AEZs are normally defined using a range of metrics, such as elevation, climate (rainfall and temperature) and soil type.

and the High Himalayas), mainly dictate Nepalese farming systems. In the Terai, the main crops are rice and wheat, while in the hills and mountains more maize is grown, as well as potatoes, vegetables, legumes and a variety of other crops.

Nepalese agriculture is predominantly small-scale farming, about half of which is dependent on natural rainfall. 46.5% of overall cultivated area is irrigated and 69.5% of total irrigable area is irrigated (MoA, 2012), although only 32% of the total irrigated land is facilitated with year-round irrigation. Irrigation development has been primarily concentrated in the Terai. Much of the irrigation comes from surface flows; however, during the winter (dry) season, this dries up and groundwater is the main resource. As a result, the intensity of irrigation in Nepal ranges considerably between summer and spring seasons. There is an increasing trend of groundwater utilisation for irrigation.

Livestock is also an integral part of the Nepalese farming system, with cattle, goat, sheep and buffalo the major livestock comprising the main species kept by farmers, with approximately 7 million cattle, 5 million buffalo, 9 million goats, 1 million pigs and 26 million poultry (DLS, 2009/10).

Agriculture is a highly climate sensitive sector. Rainfall and other climatic factors are critical to crop yields. Historically, the sector has been affected by floods, droughts and erratic rainfall and studies indicate that the performance of crop production can largely be explained by climatic variability and temporal weather conditions (Sherchand et al. 2007). Agricultural production will also be highly affected by future climate change.

2.3. The Water Sector and Hydro-electricity

Nepal has abundant water resources, with over 6000 rivers and streams, and annual surface water availability is around 225 billion m^3 (BCM) (WECS, 2011). This provides an extremely large potential resource for hydropower, irrigation, domestic water supply and industrial use, although only around 15 BCM per annum is currently in use (primarily for agricultural). However, there is a degree of temporal and spatial imbalance between demand and supply.

Around 80% of annual rainfall in Nepal occurs during the monsoon season, from June to September, and around 78% of the average flow is concentrated in just four major basins of the Koshi, Gandaki, Karnali, and Mahakali Rivers, and these major snow-fed basins maintain significant flows all year round. This is not the case for the smaller rain-fed basins that drain the Middle Hills/Siwaliks, and numerous small southern rivers of the Terai, which have low flows during the dry season.

There is a huge potential to harness the larger and perennial rivers, and a large volume of water is available in the shallow and deep aquifers, estimated to be 8.8 BCM annually (WECS, 2011), which could be used to meet the demand for irrigation and domestic water supplies.

Nepal has a very large potential for hydroelectric power. Indeed, current electricity generation is heavily reliant on hydro, providing around 90% of the nation's electricity (OECD, 2003; WECS, 2011; NEA, 2012) although overall energy needs are predominantly met from traditional biomass. The Nepal Electricity Authority (NEA) dominates power generation in Nepal but there are also a large number of independent power producers (IPPs), as well as inter-connections to India. There are 11 major NEA plants (over 5MW) with a total capacity of 459 MW, as well as 18 MW of small hydro (of which 4 MW is isolated), and 188 MW of IPP hydro plants, totaling 665 MW (NEA, 2013). Electricity sales were approximately 3040 GWh in 2012 (NEA, 2012), of which 1340 GWh was to the domestic sector and 1120 GWh to industrial: peak demand was 1026 MW.

The technical and economically feasible capacity for hydro-electricity is extremely large. A further 928 MW of hydro-power (mostly large) is currently under construction and there are plans/proposals for another 2564 MW (NEA, 2013).

Run-of-river and reservoir storage systems are affected differently by rainfall variability and river flows. The energy generation from hydro power plants is dependent on river inflows and daily poundage or reservoir capabilities. River inflows vary with climate variability, seasonally and between years. River flows are highest during the monsoon period (June to September) and lowest in January to April, which are the driest months of the year. In terms of inter-annual variability, dry years are a particular problem for run-of-river plants, and can result in increased cost of power generation due to increased thermal generation and increased imports of energy to meet shortfalls in supply.

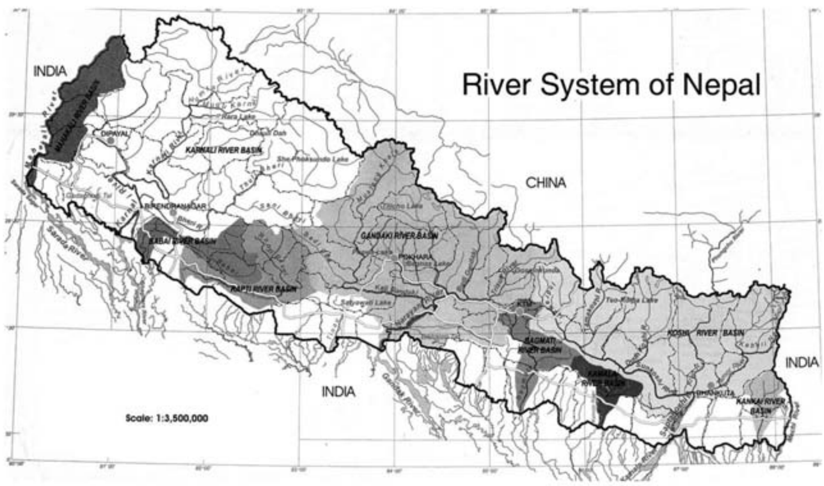


Figure 2.3. River systems and basins of Nepal.

Current electricity demand is higher than the available supply, which leads to rolling electricity blackouts for consumers (popularly referred to as 'load shedding' in Nepal), and this is affected by climate variability. Nepal's electricity generation relies mostly on the run-of-river type hydro-plants, and river flows are insufficient to operate some important plants at desired or planned capacity at times during the driest months (January to April), which increases unmet demand.

Earlier studies (USAID-SARI, 2003) have reported high economic costs from the planned and unplanned interruptions of electricity in Nepal, estimating that 8% of industrial sector demand was not met. This led to economic costs (for the industrial sector) of US$25 million a year, equivalent to 0.5% of national GDP. Power outages are likely to continue for the next 3-4 years (NEA, 2012), as demand is projected to exceed supply, and during the dry season planned interruptions ('load shedding') is projected at 12-14 hours per day per consumer.

This shows that hydropower is a highly climate sensitive sector, which is important to give the future of climate change and the plans for very large investments in the sector (see later chapters). Indeed, hydroelectricity is a major part of the medium-term development plans for Nepal (Nepal Development Vision 2030), as a source of growth and exports.

2.4. Water-Induced Disasters

Nepal is frequently affected by water-induced disasters (see Chapter 4). Floods are the major climate related hazard in the country, though landslides are also significant.

Flood inundation is the major climate-related hazard in the country, affecting property, agriculture, infrastructure (roads, bridges, communications and transmission networks), business and commerce and causing loss of life, illness from water borne disease, all of which have major economic costs to the country (see Chapter 4). Landslides, which are often related to extreme rainfall or flood events, can also have significant impact on communities and infrastructure. Floods are particularly associated with summer monsoon rains, and are a feature of current climate variability. Climate change is expected to affect these extreme events, notably through the potential increase in intense and prolonged heavy precipitation during the summer monsoon.

In addition to these rainfall-induced events, there are also current risks of Glacial Lakes Outburst Floods (GLOFs). These are the sudden large-scale release of water following collapse of a moraine (or glacial ice/moraine) dammed lake filled with melt-water, which can lead to extensive destruction, including loss of life and damage to buildings, crops, infrastructure, etc. For example, the Tam Pokhari glacial lake breached in 1998, releasing 18 million m^3 of water, causing a catastrophic flood far downstream (ICIMOD, 2012). GLOFs can also damage hydroelectric plants, and there was the loss of a multi-million dollar hydropower facility in 1985 due to a GLOF event (OECD, 2003).

Warming trends from climate change have the potential to increase the risks of GLOFs (OECD, 2003; ICIMOD, 2012). As glaciers retreat, there are projected increases in the size and volume of moraine-dammed glacial lakes, making them more prone to outbursts.

3 Methodology

Key Summary Points:

- The recent climate change literature on vulnerability, impacts and adaptation has adopted a different framework to the past, highlighting the need to focus on early time periods and consider uncertainty. The method developed here recognises this shift and has developed an analytical framework that starts with current climate variability, and then assesses future climate change, taking account of uncertainty. This uses an iterative adaptive management framework, as highlighted in recent IPCC reports.
- At the same time, recent studies have recognised that the analysis of climate risks and adaptation responses need to be assessed against the context of national development objectives and sectoral plans, and need to consider socio-institutional issues as well as technical options. This leads to the analysis of impacts and adaptation as a dynamic and evolving process, requiring different types of response activities over time.
- It is not possible to address all of these issues - across all time periods - using a single analytical method or model. However, a comprehensive coverage can be achieved by combining various lines of evidence and different methodological assessments. The study has developed a framework to do to this, breaking the analysis into a series of building blocks (work-streams) that collate the evidence base as follows:
- Work-stream 1 assesses the costs of current climate variability in Nepal in the agricultural, hydro-electricity and water-induced disaster sectors, using risk assessment and impact methods. For adaptation, it focuses on addressing short-term climate variability by building capacity and "no and low regrets" actions.
- Work-stream 2 looks at the risks to current development policies over the short-medium term in Nepal, building a current and future investment and financial flow analysis and estimating the potential costs of adaptation to mainstream resilience.
- Work-stream 3 looks at the longer term impacts and economic costs of climate change to Nepal using scenario-based impact assessment with climate projections and impact models. For adaptation, the focus has been on identifying the early action needed (in the short-term) to plan for the longer term challenges identified, taking account of the high uncertainty.
- The information from these three work streams are brought together to assess the overall impact and economic cost of climate change to Nepal over time, and to develop an adaptation pathway that responds to these risks using an iterative adaptive management approach.
- In adopting this method, the study engaged and consulted with a wide range of stakeholders. The project reported to a Government Steering Committee, which met at key points during the project. This ensured enhanced capacity, joint ownership of the project outputs, and the integrity of the national context.

- A series of stakeholder events and workshops were held with a diverse group of stakeholders. These were complemented with technical working group meetings at key points during the project. This builds the capacity of local researchers, practitioners and government officials for carrying out and using economic impacts of climate change assessments. All tasks were undertaken by local and international teams working together, and a series of training and information sharing activities were held for local researchers and government officials.
- Finally, the project undertook a needs-assessment across various departments of the Government of Nepal, and used this to design and hold a major 3-day training session with Government officials. The training was given by Nepali and international experts, with the aim of building the capacity of government officials and other key stakeholders on the methodology and approaches to assessing the economic impacts of climate change, and the use of this information for adaptation strategies and wider planning.

3.1. Introduction

There are a number of national climate change studies that assess the economic aspects of climate change. These include the mini-Stern reviews (the Regional Economics of Climate Change studies, RECCs), as well as initiatives from the World Bank (Economics of Adaptation to Climate Change, World Bank, 2009: 2010), among others. Reviews of these studies (UNFCCC, 2009; Pye and Watkiss, 2010) have found that they tend to adopt a classic scenario-based assessment, taking climate model output, and running models to assess the potential longer term impacts of climate change in the future. They then consider a range of technical adaptation options that could reduce these impacts, in some cases assessing the costs and benefits.

While these studies provide valuable information, they have a number of limitations (Füssel and Klein, 2006; UNFCCC, 2009) including insufficient consideration of immediate and short-term policy issues. They also do not take sufficient account of existing policy, or consider the full diversity of options (tending to concentrate on technical solutions). As a result, the methods that are recommended and being adopted are changing (UNFCCC, 2009; World Bank, 2012; IPCC, 2012), integrating the following issues.

- Climate change is viewed as a more dynamic process, which starts with current climate variability and the existing adaptation deficit (the failure to adapt adequately to existing climate risks), and then considers future climate change over longer time-periods.
- There is a move towards practical adaptation, with the need to consider immediate and short term time-scales, wider (non-climatic) drivers, current policies, institutional and governance issues, rather than focusing on climate information alone.
- There is recognition that adaptation involves a set of responses, addressing different problems, which moves beyond a technical response (adaptation as a process). This includes the need to address current climate variability, a focus on building adaptive capacity, the need to mainstream climate change into development, and address the issues with preparing for and tackling longer-term challenges (McGray et al., 2007: Klein and Persson, 2008), as shown in Figure 3.1 below. Adaptation also needs to be integrated with development plans, rather than being presented as a set of stand-alone actions.

- Finally, future climate change is uncertain, and tackling it requires a different approach to optimization, instead focusing on decision making under uncertainty. This is often framed around adaptation as a pathway (Downing, 2012). This new approach was reflected in the IPCC Special Report on Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation (SREX, IPCC, 2012) which highlighted the potential role for iterative risk management (monitoring, research, evaluation, learning, and innovation), portfolios of action (rather than a single focus), and for measures that provide benefits under the current climate as well as providing resilience for the future, which are termed no-or low-regrets measures, and for future responses that encourage flexibility and robustness.

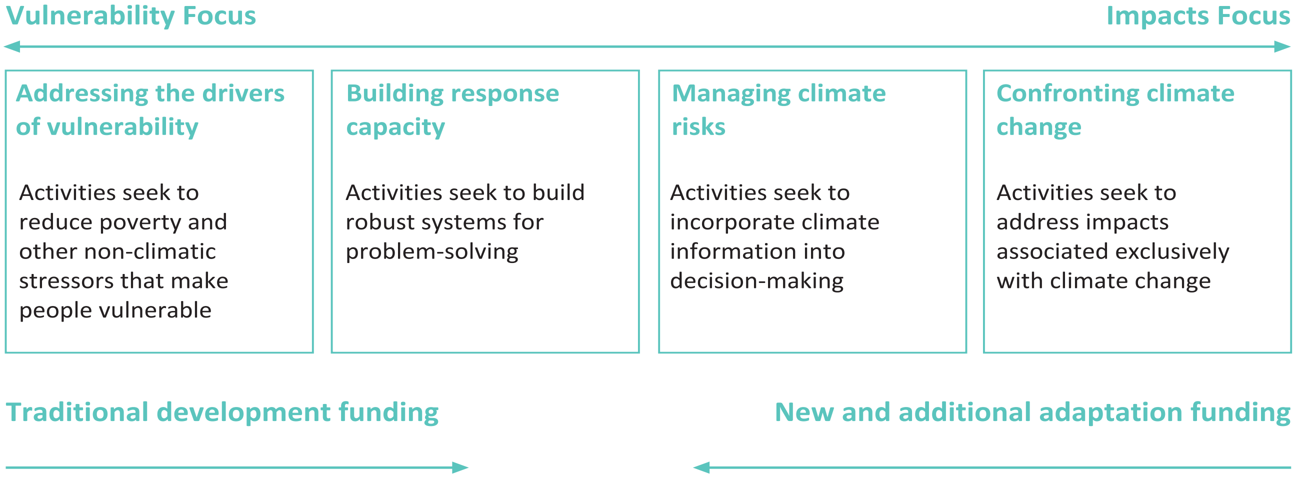


Figure 3.1. Adaptation as a continuum: from addressing the drivers of vulnerability to confronting the impacts of climate change

Source: Klein and Persson (2008).

A climate compatible growth pathway will need to take all these issues into account. However, it is not possible to address all of the above elements using a single analytical method or model. Instead, the study has developed a series of building blocks (work-streams) that together collate the evidence base and look at potential responses.

3.2. Early Review Findings

As part of the early work on the study, a detailed review was undertaken (published in an inception report, IDS, 2012). This review found that there was already a very large number of studies of climate change in Nepal. These national level documents include the 1st National Communication (GoN, 2004), the National Adaptation Programmes of Action (NAPA, GoN, 2010), the Local Adaptation Plans of Action (LAPA), the Strategic Program for Climate Resilience (SPCR), among others. A large number of literature papers (both academic and grey) were also reviewed. Finally, the review identified a number of major initiatives, including work on disaster risk management and agriculture and climate change (as part of the SPCR), assessments of the impacts and economic costs of climate change as part of regional Asian studies (for the Asian Development Bank), and work on climate finance (ODI, 2011; 2013) and climate resilient planning (GoN, 2011). Where possible, the study has built on these existing studies, to provide Nepal specific context, and to avoid duplication.

3.3. Methodology

Based on the issues outlined above, the study developed an approach that started from the present, and looked at the issues of current climate variability and climate extremes, including their economic costs. This is crucial to understand the current adaptation deficit. However, it was also recognised that the analysis needed to be grounded in current Government policies, including development and sectoral plans, to assess risks and possible resilience options over the medium term (e.g. consistent with the long-term development vision to 2030). This starts the process of embedding (mainstreaming) climate change into current development. Finally, with respect to the long-term impacts of climate change, a key issue to consider was uncertainty. Reflecting these issues, the study was split into three work streams addressing different time periods and adaptation responses:

1. **The cost of current climate variability and extreme events in Nepal.** This provided the analysis of near-term economic cost, including potential impacts from changes in climate variability. For adaptation, the focus was to addressing short-term climate variability (now and for the next 5-10 years) - focusing on building capacity and identifying short-term, "no and low regret" actions. The primary method used for this step is based around risk assessment.
2. **The risks to current plans over the short-medium term in Nepal.** This provided an initial risk screening of the potential impacts of climate change on current plans. For adaptation, the study focused on the costs of building climate resilience into existing plans (for the next 5-20 years). The primary method used for this step is based on investment and financial flow analysis.
3. **The longer term impacts and economic costs of climate change to Nepal.** This provides an analysis of the impacts and economic costs of future climate change in key sectors, using information from climate model projections and impact assessment models. For adaptation, the focus was on identifying early actions needed to address these long-term challenges. The primary method used for this step is scenario-based impact assessment.

The three work-streams are illustrated in the Figure below.

Overall, this builds on the concept of adaptation as a pathway (Downing, 2012), providing a set of complementary activities to address current risks, mainstream adaptation, and address longer-term challenges, within a consistent framework towards climate compatible growth. This shift towards iterative adaptive management framework (also known as iterative risk management) was recommended in the recent IPCC SREX report (IPCC, 2012).

The key difference of this approach from previous work is that it shifts away from a predict-then-optimise framework to a dynamic pathway that incorporates uncertainty, allowing adaptation to work within a process of learning and iteration (as part of a cycle to improve future strategies). This emphasises early low and no-regret options, as well as early activities to prepare for uncertain future change. It also produces information on impacts and economic costs that has high relevance for real adaptation assessment and planning. The key advantage of the approach is that rather than taking an irreversible decision now-which may or may not be needed depending on how climate change evolves-it encourages decision makers to ask "what if" and develop a flexible approach, where decisions are adjusted over time with evidence (Reeder and Ranger, 2011). This helps ensure the right decisions are taken at the right time.

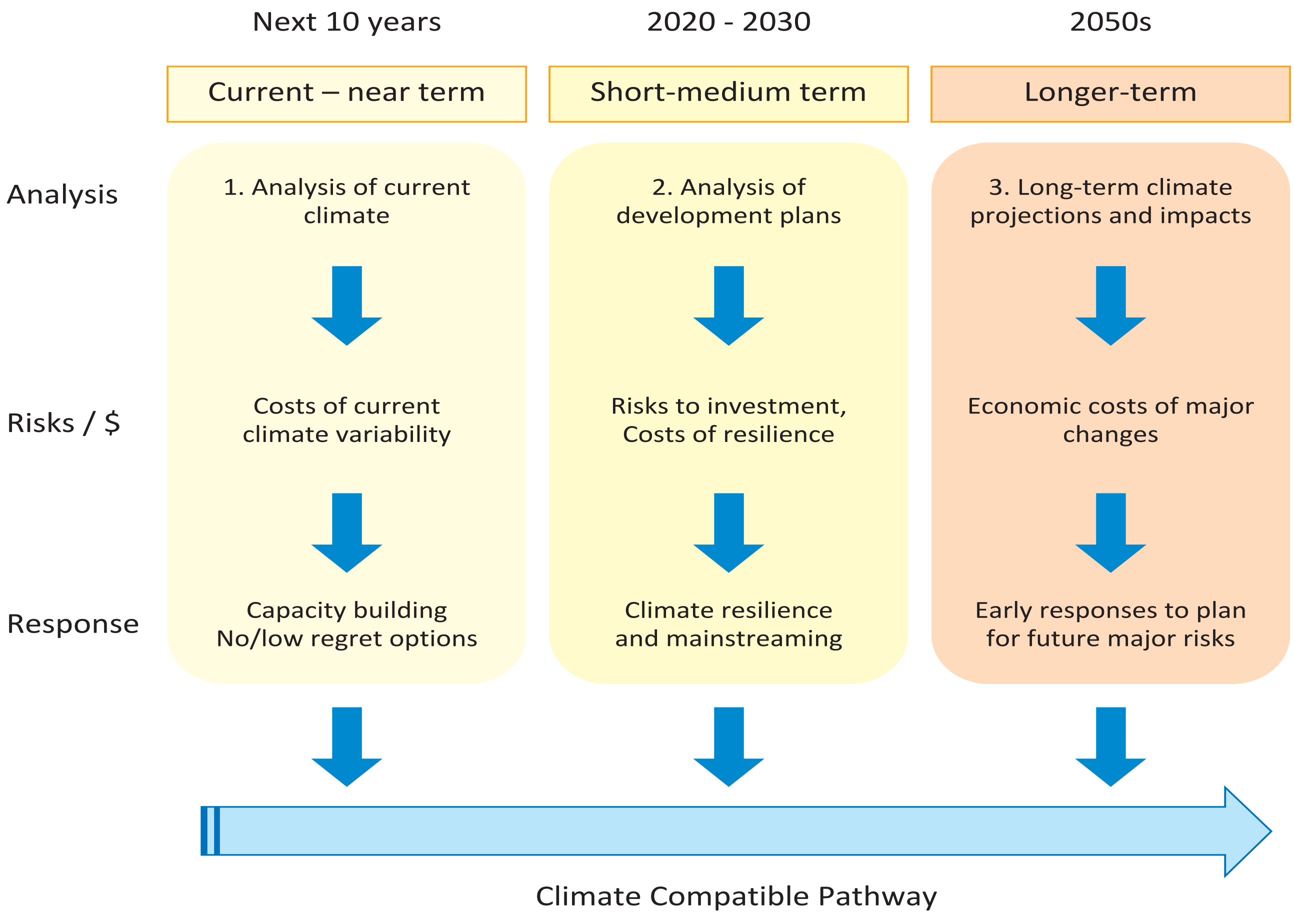


Figure 3.2. Overview of the project methodology

Source: GCAP.

This method has been applied at a national level, but is also aimed wherever possible to differentiate between the three major agro-ecological/climatic zones, i.e. the Terai, Hills and Mountains, to assess what impacts and economic costs arise in each of these zones, and to consider appropriate options for different areas of the country.

3.4. Method for Work-stream 1: Current Climate Variability

The primary methods used in work-stream 1, which is focused on current climate variability, are based around risk assessment and analysis. This involves a broad range of techniques, which depend on the nature of risks and the information available for each sector.

The analysis of water-induced disasters focuses on the impacts of these extreme events and the associated economic costs. This includes the physical damage to tangible assets (e.g. buildings) but also the effects on intangibles effects such as loss of life or injuries. Given the scale of some flooding events, there is also a need to consider the wider or indirect effects of such events, e.g. the knock-on effects on industrial production.

There are a number of alternative methods for assessing the current effects of water-induced disasters, which involve different levels of sophistication. All are based around risk analysis, i.e. considering the magnitude and probability of events. In an ideal analysis, detailed flood risk modelling systems use hydrological models to build up an understanding of flood risk frequency, which are linked to hazard or impact maps and models, with the use of damage function based on historical events (e.g. as in Rojas et al., 2013). Such approaches can be used to build up a detailed probability risk curve showing the frequency of floods of different return periods (e.g. 1 in 10 year event, 1 in 100 year event) and the associated impacts and damages associated with each type of event, thus providing assessment of the overall expected annual damage. This method is most robust when undertaken at the river basin level. Work is underway in Nepal to build up these types of systems and assessments. The same methods and models can also be used to assess the changes from climate change, assessing how climate change affects the frequency and intensity of events and related flood damage. Such an analysis has not been undertaken at the national level in Nepal yet, but it has been undertaken in the Lower West Rapti Basin (see case study later).

However, it is possible to build up a simpler picture of expected annual damage at the national level by analysing historical events (analogues). This is the approach used in this study, using existing datasets, but also extending these data to quantify and value a greater number of impacts to provide a more complete estimate of current economic costs. The study has first taken data from the Government of Nepal on natural disasters including floods and landslides, both of which area associated with rainfall. While the datasets provide information on property damaged and total loss, additional analysis has been undertaken to assess the potential economic costs for fatalities and injuries, livestock losses, and welfare losses from disruption. To do this, the welfare loss associated with such impacts was estimated through the use of measures of the willingness to pay (WTP) in monetary terms, to avoid impacts. The analysis has been undertaken at national level, but also disaggregated to local level.

For the analysis of health impacts, the value of a prevented fatality (VPF) - also known as the Value of Statistical Life (VSL) - is derived from estimates of the WTP for given annual risk reduction. In the absence of specific Nepalese values, we have transferred values from Lindhjem et al. (2011) and Alberini et al. (2006) to provide a range of values - base values - and adjusted these in line with relative income levels (expressed in purchasing power parity (PPP) terms) and the elasticity of the marginal utility of income (expressed as E using a range of values (E = 1; 1.5; 2), reflecting higher utility from additional income in low income countries, Hammitt and Robinson, 2011). The range of VPF values are summarised in Table 3.1, below, presenting the low, central and high estimates from the combinations considered. It is highlighted that a small number of studies have been published for India, and their results show a range of US$150,000 to US$1,400,000 (Bhattacharya et al. 2007; Shanmugam, 2006).

Table 3.1. Health Valuation Estimates (US$, 2013 prices)

	Low value	Central value	High value
VPF (Base values)	1,634,000	5,650,000	8,330,000
VPF (E = 1)	41,702	144,187	212,601
VPF (E = 1.5)	6,662	23,034	33,964
VPF (E = 2)	1,064	3,680	5,426

A single value of US$379 (2013 prices) per household per year for disruption is derived on the basis of a transfer from a study by Floyd et al. (2003).

For the agricultural sector, analysis has also been made of additional climate related events, focusing initially on droughts. While these are not as common as floods, there have been major drought events in recent years. The valuation of the direct effects of these events has been undertaken by investigating productivity losses, valued using market prices. World market prices are most applicable as they effectively represent the opportunity cost to the country of the commodity production. World prices for wheat, maize and rice have been taken from the FAOSTAT Database, averaged over the period 2006-2010, giving values (updated to US$2013 prices) of US$289/tonne (wheat), US$252/tonne (maize) and US$611/tonne (rice). However, domestic prices are also considered as a sensitivity, due to the fact that not all production will be traded, or because trading is distorted by neighbouring markets. Domestic prices are taken from FAO (FAO GIEWS Price Tool: Kathmandu Market; FAOSTAT), and for the same period, prices are reported as US$398/tonne (wheat) and US$462/tonne (rice), noting maize is not in the statistics. It should be noted that under the Agriculture Perspective Plan, (1996-2015), price support policies are not used. Thus, the domestic prices effectively reflect free market conditions. Additional climate related risks associated with inter-annual variability and soil erosion have also been investigated.

For hydro-electricity, analysis was based on the effects of climate on planned outages (unmet demand), looking at the variability between years during the dry season. The analysis of the economic costs associated with electricity supply considered the following two issues. First, the value that industrial consumers place on an incremental unit of electricity supply provision, which is equal to the net profit from the increase in output due to the additional electricity. These values differ by industrial sector. An earlier study in Nepal (USAID-SARI, 2003) estimated these values, and updating to current prices, indicates a value of US$1.5/kWh (2010). Second, the value of lost load (VOLL) when electricity is not supplied. USAID-SARI (2003) also estimated VOLL for Nepal and these have been updated to 2013 prices. The VOLL are estimated at $0.9/kWh (2010) for unplanned interruptions and $0.3/kWh for planned interruptions for industrial consumers. No values are available for household/domestic consumers.

The focus in work-stream 1 is at the national level. However, the inception study found a high level of spatial variation in impacts across the country and large differences in the distribution of these impacts across groups in society (by gender or income level). To explore these issues, two local case studies using primary household surveys were undertaken to complement the national level focus.

3.5. Method for Work-stream 2: Investment and Financial Flow

The method used for work-stream 2, which looks at the medium-term to 2030, is based on investment and financial flow (IFF) analysis. This considers the risks to on-going development programmes, and involves an assessment of the costs of building climate resilience into future investment plans. This looks at climate change mainstreaming within the context of existing development objectives and budgets. This part of the study is important for two reasons. First, it grounds the analysis of adaptation in the institutional and existing programmatic structure in Nepal. Second, there are large existing programmes already operating in Nepal. Most of them have already included many of the early no-and low-regret adaptation options. Furthermore, some programmes have already mainstreamed climate change in future budget lines. There is therefore a need to take this existing baseline into account, and look at the additional financing needed for adaptation.

The methodology applied for this work-stream derives from the UNDP Investment and Financial Flow (I & FF) analysis guidance (UNFCCC, 2010), which has been piloted in 19 countries. It concentrates on national level policy and looks over the next 5 to 20 years - in line with Nepal's development objectives-thus aligning with planned development. The IFF approach considers resilience and adaptation activities already under implementation through existing programmes and projects using a form of Public Financial Management (PFM) assessment. This is particularly relevant for water and agriculture related sectors, where there is a high degree of overlap between good development and climate resilience, but where many programme activities may not be explicitly labelled as adaptation. Investments range in type and scale from household resilience investments, to corporate and government investments in infrastructure, and programmatic support for capacity building and outreach. Sources of funding include both domestic and foreign funds, and private and public funds. The method involves three key steps:

- First, an analysis of the baseline investment and financial flows in relevant sectors (a baseline scenario);
- Second, a risk screening of existing major policies and programmes;
- Third, an analysis of the additional sectoral adaptation and investment needed (an adaptation scenario), identifying total investment needs (expressed as an annual and present value, using a 10% discount rate).

The baseline and adaptation scenarios are compared to determine the change in investments needed to address the adaptation challenge in the sector. This draws on information from work-streams 1 and 3. Note that changes may include increases in investments (new funding), but also reallocation of existing investments. Finally, the opportunity to revise policy frameworks in line with the resilience challenge is explored.

The baseline profile was based upon the best available programme and project data provided through the MoF budget planning and reporting processes. The share of off-budget and private sector investment were estimated on the basis of MoF reporting, supported by expert opinion and discussions with GoN officials. The projections assumed steady growth in the relevant budgets based on assumption set out in publically available strategies (e.g. Agricultural Development, Water and Energy Vision).

It should be noted that the future baseline is indicative, i.e. it is not an official commitment by the GoN or other stakeholders. However, they can support the government to articulate the funding implications of adaptation investment, to help engage with climate finance funding, and to help communication within and across Ministries and government agencies.

3.6. Method for Work-stream 3: Scenario Based Impact Assessment

The final work stream, which focuses on the long-term impacts and economic costs of climate change, uses scenario-based impact assessment method. This is the standard approach used in assessing the longer-term impacts and economic costs of climate change in national studies. The method starts with the selection of climate model simulations of future climate change, for defined future emission scenarios, and then quantifies the physical impacts of future changes, assessing the corresponding economic damages (Carter et al., 2007). The analysis of impacts can be undertaken using impact functions that link climatic parameters to physical impacts, though this is often integrated within impact assessment models. The discussion of climate model projections - and their results for Nepal - is covered in a later chapter. In summary, the study has used downscaled regional climate model simulation projections for Nepal, focusing on a medium-high emission scenario - the SRES A1B scenario (Nakićenović et al., 2000), but with interpretation of uncertainty from other model runs (including the DHM portal) and statistically downscaled climate model results (UCT, 2012). The projection data were then combined with sectoral impact methods and models, as detailed below. For the two water sector assessments, an additional step was involved to convert the climate model data to flow changes using a hydrological model.

Agriculture

For the agricultural sector, the impact analysis has been undertaken using a well-known crop simulation model, the Decision Support System for Agrotechnology Transfer (DSSAT) (Hoogenboom, et al., 2010). DSSAT is a process-based computer model that predicts growth, development and yield as a function of local weather and soil conditions (soil-plant-atmosphere dynamics), crop management scenarios and genetic information. The model uses daily weather data, soil profile information, and basic crop management data as inputs. While the model can be used at farm level, it can also be used at the national level to look at the impact of climate change. The outputs are compared with local experimental data in order to evaluate model performance and determine the genetic characteristics of local varieties.

The study has applied the DSSAT model (Version 4.5) to look at the three main crops in Nepal: rice, wheat and maize. A key factor is to work at a level of spatial disaggregation that reflects the earlier discussion of agro-ecological zones. To do this, the study split Nepal from east to west horizontally and in terms of elevation into the Terai (plains), Mid-hill and Mountains vertically. This resulted in nine major aggregation areas, i.e. Solukhumbu (mountain east), Dhankuta (mid-hill east), Sunsari (terai east), Mustang (mountain central), Lalitpur (mid-hill central), Rupendehi (terai central), Jumla (mountain west), Surkhet (mid-hill west) and Banke (terai west). The application used observed crop data for validation, based on Coordinated Varietal Trial (CVT) data (3 years data for rice, one year for maize and four years for wheat). Crop periods were selected to match seasonal timing in the regions. The climate model projections for the time slice 1972-2070 (see later) were used, with analysis of yield changes with temperature and precipitation. Additional analysis was included to consider with and without the effects of CO_2 concentration.

The DSSAT model produced estimates of the changes in crop productivity, output in tonnes/hectare. By combining with land area, these changes in productivity can be valued using market prices. Two sets of market prices are potentially relevant for this calculation: world prices and domestic prices, as discussed in work-stream 1. A further sensitivity was also undertaken to look at future prices, which are affected by the combination of socio-economic scenarios and global climate change (i.e. on other suppliers and trade effects). The analysis of the effects of future climate change was based on a review of price profiles with climate change to 2100 from Easterling et al. (2007). The sensitivity analysis used the changes in output cereal prices from Parry et al. (2004) as a proxy for the three commodities, based on the A2 scenario. It should be noted that there is very significant uncertainty in this approach; a lower-end estimate from Darwin (2004) would have led to very low impacts.

Water Sector Impacts

For the water sector analysis, the first step was to take the climate information and feed this into a hydrological model to analyse the changes to water availability and river flows. The analysis initially used PRECIS model output (based on the GCM Had CM3) provided by IITM (Indian Institute of Tropical Meteorology, Pune) for the A1B scenario, working with a resolution of 50km x 50km, from 1961 to 2099 (see chapter 5). However, in order to capture some climate model uncertainty, DHM Data for PRECIS using the ECHAM5 parent GCM was also used. The analysis first undertook bias correction of the data, to align observed and modelled hind cast data. Bias correction is needed because although regional climate simulations improve the reality of the outputs climate, these models still have biases compared to the actual observed climate. For a country such as Nepal, which has a very complex climate, it is necessary to apply bias correction for water-based impacts (notably flood risk and daily river flows) to make sure the model outputs are more closely aligned with the observed climate.

The analysis used a rainfall-runoff model for selected catchment areas to derive the stream flows for different future climate periods. This was based on the projected monthly rainfall at points of interest (river basins). This revealed major differences between the two alternative climate model simulations (i.e. from the two parent GCMs used in the same regional climate model). While the ECHAM5 GCM-PRECIS results showed a little change over time in annual and monsoon precipitation the Had CM3 GCM-PRECIS results showed a major increase (upto 50%) in annual, pre-monsoon and monsoon precipitation to 2030, followed by a major reduction through to 2060. The comparison of annual precipitation from the two models is presented below. This underscores the need for using an ensemble of projections with different climate models and scenarios, rather than only one model. Given the uncertainty, it is recommended that future studies need to sample even more widely (across GCM-RCM combination), while noting that doing so involves considerable time and resources.

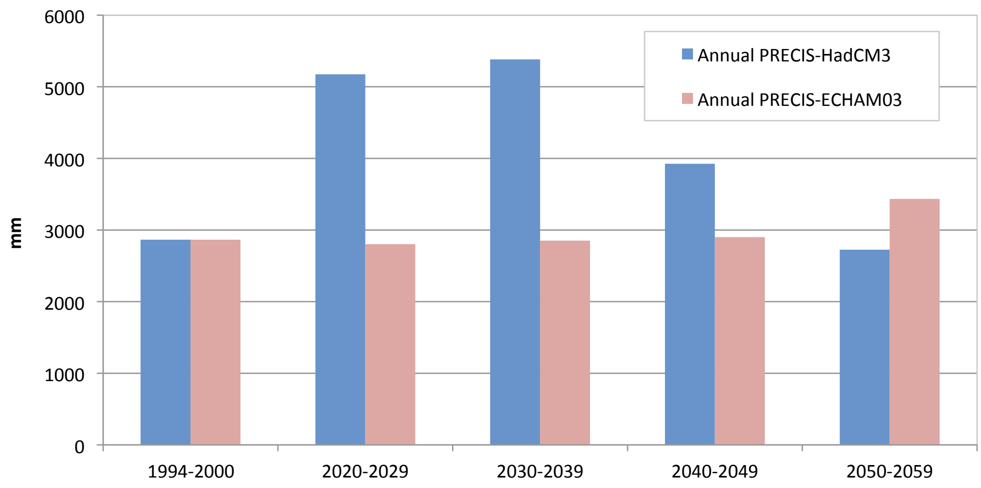


Figure 3.3. Comparison of Historical and CC Projected Rainfall at Sundarijal

The final step was to use statistical analysis (derivation of Flow Duration Curves and Flood Frequency Analysis using observed and simulated stream-flow data) to assess the impact of climate change on hydrology (stream-flows):

- The flow duration analysis was used to assess the impact of climate change on hydro-power generation.
- The changes in flood frequency were used to assess changes in the risks of water-induced disasters.

Initially, a monthly conceptual, lumped hydrological model, the Tank model, was used to simulate the stream-flows in six selected catchments. This is a simple model composed of several tanks arranged vertically in series. Water in each tank partially discharges through a side outlet or outlets and partially infiltrates through a bottom outlet to the next lower tank. River discharge can be simulated as the sum of outputs from the side outlets. The monthly Tank Model was run in six sub-basins for the A1B climate projection using bias corrected data from the PRECIS RCM model using the Had CM3 parent GCM. In line with the example above, this showed that the future projected flows were much higher than the historical flows in all seasons for the period 2030-2060. This compared to the data from the PRECIS model using the ECHAM5 parent GCM, which showed much smaller changes. These can be seen below in the flow duration curves, which show the % of time that the daily mean flow discharge is exceeded (the x-axis shows the percentage of time in a year where flow is equal or more than the given y-axis value).

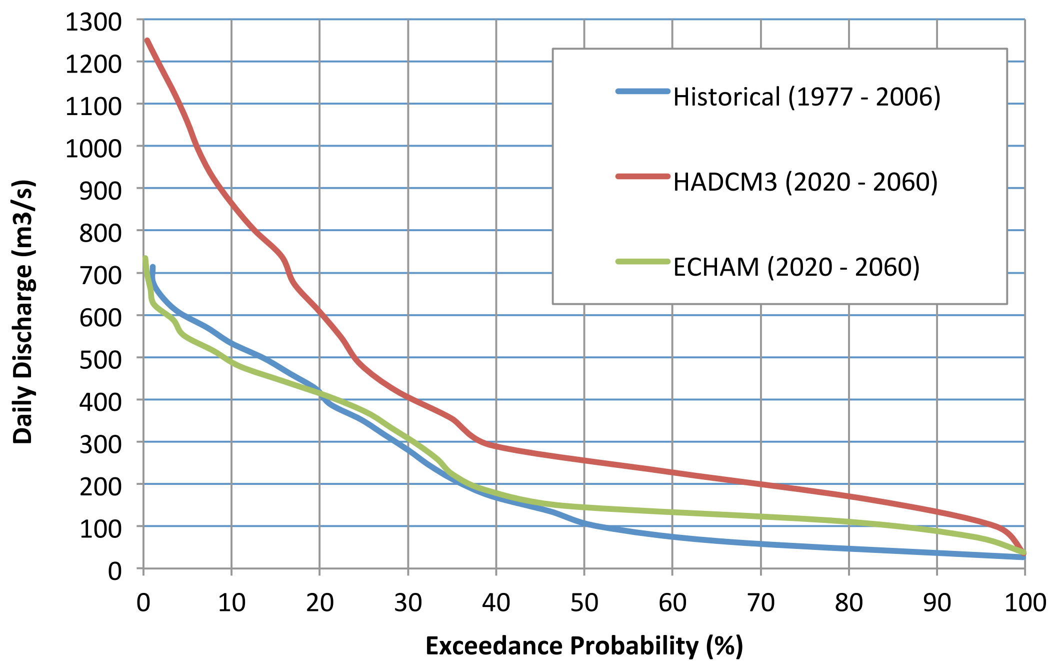
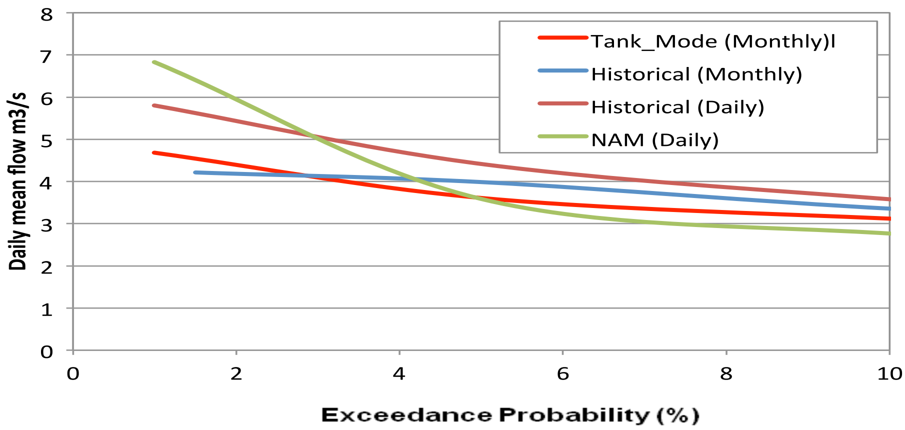


Figure 3.4. Example of the Annual Flow Duration Curve for Budhi Gandaki River Basin at Proposed Dam site

The daily flow results from the monthly Tank model were compared to a daily model, NAM (shown in the Figure below). It was found that the monthly Tank model did not accurately model the variations in precipitation expected from climate change as well as the daily time step NAM model, i.e. the monthly aggregation was not adequately representing within-month variability. This variability is particularly important in relation to low flows, as these affect run-of-river generation, and for high flows in relation to water-induced disasters. The monthly model overestimated low flows, and underestimated high flows, thus it underestimates potential impacts in both cases.



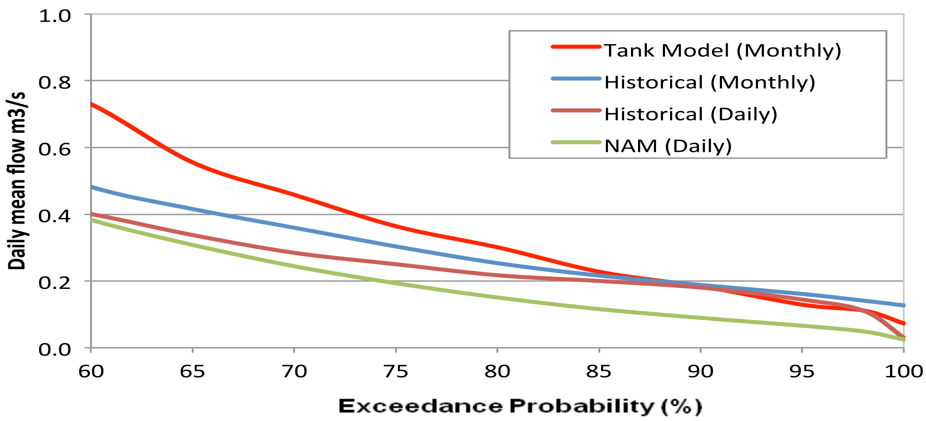


Figure 3.5. Comparison of Annual Flow Duration Curve of Bagmati River at Sundarijal. Top high flow, Bottom low flows

As a result of this comparison, the team decided that it would be better to use more detailed daily hydrological analysis to complement the monthly analysis. However, running daily models is resource intensive and time consuming, thus it was not possible to do this for a large number of catchments. Instead, the study drew on ongoing research/work by the team in two other river basins. This included the Tamor sub-basin in Koshi River Basin using the SWAT model (daily time period) with both the IITM and DHM (PRECIS Model using ECHAM5 parent GCM from DHM Climate Portal) and the NAM modelling of the Bagmati at Sundarijal.

Hydro-electric power

The energy generation from hydro-power plants is dependent on the river inflows and reservoir capabilities of individual plants, noting that run-of-river and storage systems are affected differently. River inflows do vary with climate variability, seasonally and between years. River flows are highest during the monsoon period (June to September) and lowest in January to April, which are the driest months of the year. In terms of inter-annual variability, dry years are a particular issue and can result in increased cost of power generation due to increased thermal generation and increased imports.

For the analysis of the impacts on hydro-electric power, a linked modelling system was used, comprising of the VALORAGUA and WASP (Wien Automatic Simulation Planning Package) models. This integrated analysis uses the VALORAGUA to link to hydrological flow analysis with hydro-thermal system optimisation, and the WASP model to look at the overall system and expansion plan optimisation. The main focus of the study was to look at the change in low water flows, which are important for run-of-river plants.

The VALORAGUA Model comprises of several modules that perform the management of a mixed hydro-thermal electric power system. It establishes the optimal strategy of operation for a given power system by the use of the "value of water" concept (in energy terms) in each power station, for each time interval (i.e. month/week) and for each hydrological condition. For hydro-power plants, the model takes into account that the water may have other utilisations rather than energy generation. The model can be used to determine optimal operating strategies for a given configuration of the electric power system. It minimises power system plant operation costs on various time periods (annual, monthly, weekly) and allows modelling of the hydro system for seasonal variations, to optimize the system operation and maximise the hydro output. It takes account of running cost, namely fuel cost and cost of unserved energy. Using input data (reservoir storage capacity, dead volume level/volume water level and average operation costs), the model optimises the management of reservoirs by minimising the expected value of future generation costs and performing the management of the electric power in order to minimise the sum of generation costs and the expected value of future generation costs.

In the study, the VALORAGUA analyses were used a 30-year baseline hydrology data set, with an analysis of the probability of certain years with five types of conditions, e.g. very wet (10%), wet (20%), average (40%), dry (20%) and very dry (10%), and analysed annual flows and energy generation. For run-of-river plants, energy generated is proportional to river inflow. For storage plants, reservoir operation simulation is also required. Five representative rivers (Chamelia, Nalsyagadn, Budhi Gandaki, Kulekhani, Upper Seti) were considered, and the flow conditions in nearby rivers were derived by extrapolating flow conditions in these rivers. VALORAGUA was used to estimate the optimal operational strategy and the output (total annual flows) was fed as an input to WASP.

WASP is an electricity system planning tool and was used to look at the overall electricity generation system in Nepal for the future, with and without the effects of climate change. WASP helps to find the economically optimum expansion plan for a power generating system in the future, within constraints specified by the planner. Historically the public utility, Nepal Electricity Authority (NEA) used WASP for generation planning exercises, though it has not been carrying out such exercises in recent years. To run the model, WASP requires that the technical, economic and environmental characteristics of all existing power plants in a country's electricity generation system are defined, as well as information on candidate (future) projects. The characteristics include plant capacities, minimum and maximum operating levels, heat rates, maintenance requirements, outage rates, investment costs, fuel and operation costs, emission rates, etc. It uses the load forecast and outputs of VALORAGUA with and without changes in hydrological flow as part of this, allowing analysis of hydrological information and power generation. Using this plant level information, WASP helps to find the economically optimum expansion plan for the overall power generating system in the future for a given yearly future demand for electricity over the planning horizon.

To do this, the model explores all the possible sequences of capacity additions that will match demand, and at the same time satisfy all constraints, for example a certain level of system reliability, availability of certain fuels, build-up of various technologies, or environmental emissions. The model evaluates combinations of candidate generation projects to obtain the least-cost expansion plan (optimal solution) for a given period. Each possible sequence of power plants that could be added to the energy system, for example an expansion plan or policy, and which meets selected constraints, is evaluated by a cost function of capital investment costs, fuel costs, operation and maintenance costs, fuel inventory costs, salvage value of investments and cost of energy demand not served. The outputs of WASP include the alternative expansion plans and their Present Value (NPV) costs and annual financing requirements. WASP is a cost minimisation tool whose objective function is to generate the power planning expansion plan with the lowest present cost for the planning period. The model is probabilistic and not deterministic. WASP measures system reliability with three indices namely: i) Reserve margin; ii) Loss-of-load-probability (LOLP); and iii) Expected Energy Not Served (ENS). These reliability indices and the maximum number of thermal or hydro-electric units that can be added each year are entered into the model as user-specified constraints that an expansion plan must meet to be acceptable.

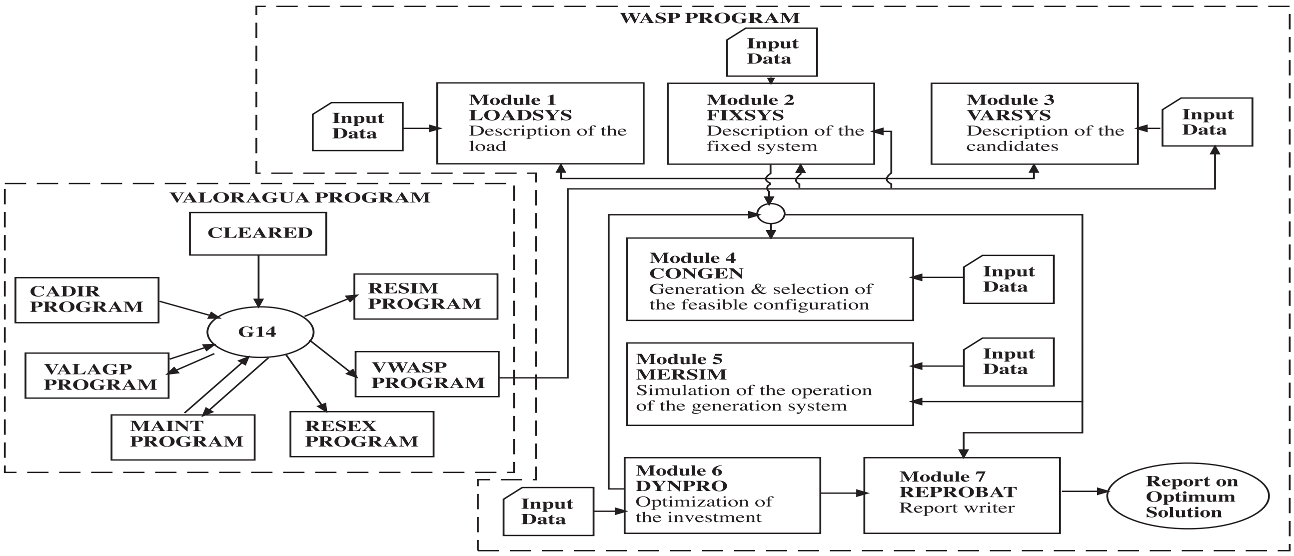


Figure 3.6. Integration of WASP and VALORAGUA models for power generation investment planning

The baseline analysis in WASP was based on a NEA system, which in 2013 (NEA, 2013) had a total installed and connected capacity of 762 MW, of which 709 MW was hydro (478 from NEA, 231 from IPPs). This includes 30 existing hydro-power plants (ranging in size from 5 MW up to 456 MW) and 2 thermal plants (total 49MW). The study collected information on planned plants (in construction or planned) to assess the total capacity of existing and committed hydro-power plants. Information on 32 candidate plants was collected. These include a very large level of possible capacity, totaling around 20000 MW, including a number of large plants, and one very large development (the 10800 MW Karnali Chisapani storage dam project). Capacity, energy and cost data for these hydro power plants were based on study reports prepared by NEA. This included the Nationwide Master Plan Study on Storage Type Hydro-electric Power Development in Nepal (Draft Final Report, 2013), the Feasibility Study of Hydro-Power Projects carried out by Canadian International Water and Energy Consultants (CIWEC) in 1998 and other project study reports prepared by NEA. Costs of candidate power plants were taken from feasibility study reports and escalated to current price levels. These plants include both run-of-river plants, where there is little or no control over the discharge, and thus the daily discharge is the natural flow of the river; and storage plants, where there is reservoir for flow regulation. In the analysis, the hydro plants were divided into three categories: run-of-river (RoR) without regulation, RoR with small regulation where storage in reservoir is low compared with river flow, and storage (or reservoir) type.

For the economic analysis, the inputs to the WASP model were capital, fixed operation and maintenance (O&M) costs of hydro-power, energy not served and transmission costs. The operation and maintenance costs were based on the 2008 NEA Generation Expansion Plan. The analysis assumes an economic lifetime for a hydro plant to be 50 years, and uses an internal discount rate of 10% in real terms, based on the assumed economic opportunity cost of capital - which is in line with the rate used for the power sector and, in general, for the evaluation of public sector projects in the country. The cost of un-served energy is UScent 29.6/kWh which is also the figure used by NEA.

It is stressed that the analysis estimates the damage costs and the value of energy not served (ENS) within the modelling environment, but then goes on to estimate the additional capacity investment needed to meet demand, i.e. strictly speaking, this is an adaptation cost, used as a proxy for damage costs.

The NEA has carried out load forecast up to 2025 (Load Forecast, 2008, NEA). NEA uses econometric methods for load forecasting. The load demand is assumed to increase at an average annual rate of 7.8% till 2029 and 7.1% thereafter. The peak load and energy forecast is presented in the figure below. The forecasts were extended out to 2050 for analysis. By 2050, the load (MW) and the Energy (GWh) required will have risen significantly.

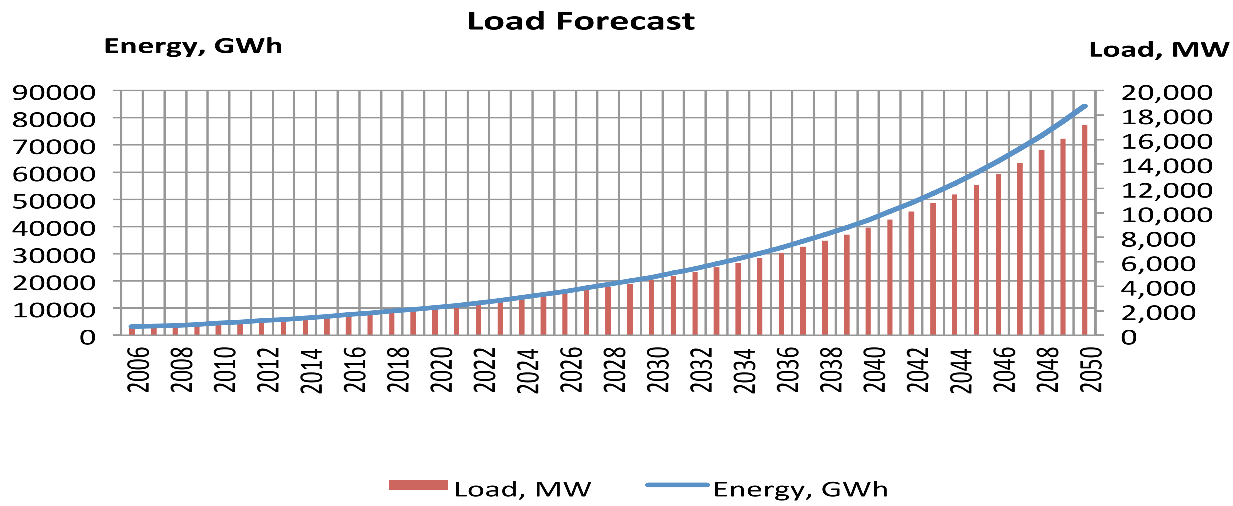


Figure 3.7. Load forecasts for Nepal

Source: NEA.

Note that these load forecasts do not take account of the future impacts of climate change in raising electricity demand for cooling, thus they potentially underestimate future demand, though they also do not take account of the reduced demand for heating. Further work to explore the likely impact of climate change on future demand is highlighted as a research priority.

Water-Induced Disasters

For water-induced disasters, the hydrological modelling analysis for hydro-electricity (outlined above) were used, but analysed in terms of changes in high water flow. The analysis looked to assess potential changes in terms of changes to the magnitude and frequency of high flows, noting that flood damages increase with higher water levels and stream velocities, i.e. whether there are changes in the magnitude of a 1 in 10 or 1 in 100 year flood, or a change in the return period of a specific high flow. As above, the bias corrected rainfall and Tank model was initially used. However, this did not capture daily high flows and high flows sufficiently. Therefore, a similar approach was adopted for the analysis, using results from other ongoing research/work in two river basins – Tamor and Bagmati. These were collected and analysed to define the future changes in the flows due to climate change.

Flood frequency analysis is normally carried out using instantaneous annual maximum flood values but these were not modelled, as the time-steps of both SWAT and NAM models were on a daily basis. Hence, a ratio of flood estimates using observed instantaneous annual maximum flood values and the annual daily maximum flood values were used to estimate the modelled instantaneous annual maximum flood estimates for different climate change scenarios in both study catchments. The results are reported in Chapter 7.

For valuation, the analysis applied the same approach to value market and non-market impacts as with the analysis of water-induced disasters in work-stream 1. However, in addition to the changes in high flow from climate change, it is important to consider the changes in socio-economic trends, notably population and assets at risk, as climate change occurs in a future that will be different from today. All other things remaining constant, if population increases, impacts will also rise in line with the number of people potentially exposed to the climate risk.

However, the effect of population growth on exposure to water-induced disasters will also change with projected economic growth. The effects of growth are complicated. While increasing growth will increase assets at risk and the potential level of damage, higher wealth is associated with higher adaptive capacity and greater levels of baseline protection, which would reduce the vulnerability of a population to a given risk. The increase in GDP/capita is expected to be greater than the growth in population in the period up to 2030. Future baseline multipliers were derived, based on population and growth forecasts, asin Table 3.2 below.

Table 3.2. Socio-economic multipliers relative to 2010 - Nepal

	2015	2020	2025	2030	2050	2070	2100
Population	1.09	1.17	1.26	1.33	1.55	1.62	1.50
GDP/capita	1.26	1.90	3.10	5.41			

Finally, the analysis of the sectors above provides direct damage costs. In all cases, prices are expressed in constant (2010) prices. They are presented in undiscounted terms initially, to allow direct comparison over different time periods. It is noted that for subsequent analysis in adaptation policy, there is a subsequent need to discount these values as part of a net present value calculation.

However, effects of climate change will also lead to additional wider or indirect economic costs. These include effects which may arise as impacts in one sector affect other sectors, from changes inprices and demand, as well as macro-economic effects (measured through such indicators as GDP, employment and investment, imports and exports). These effects can be analysed through the use of Computable General Equilibrium (CGE) models, however, such an analysis is only possible if the existing CGE models for Nepal have a structure that lends itself to the analysis of climate related outputs. The potential for using CGEs was explored in the study, and it was found that none of the existing CGE models could cover all of the impacts of high relevance in the study (e.g. while it is possible to include consideration of agricultural productivity, there was not sufficient sectoral detail or categories to allow consideration for hydro and water-induced disasters).

However, there is the potential for impacts, notably in the electricity sector, to have strong inter-linkages and inter-dependencies with other sectors, by affecting input costs for final products. To investigate these effects, the study has analysed where the inter-dependencies are likely to be strongest using input-output analysis, based on data from Raihan and Khondker (2011).

Finally, it is highlighted that in some sectors - notably in agriculture and regional electricity generation - the economic costs of changes in productivity in Nepal will be heavily influenced by regional and global scale effects, and changes in production, prices and trade. While detailed regional or global modelling has not been possible, these are highlighted as an important issue for future studies.

3.7. Key Assumptions

A number of key assumptions are involved in the study. These are summarised below.

Current GDP and exchange rate into US$ is based on UN statistics. A common price year of 2013 is used for the direct cost analysis and IFF assessment, with exchange rates based on September 2013. For work-stream 1, costs are presented in US$, and expressed as an equivalent % of current GDP (2013 prices). For the analysis of sector investment costs, the investment and financial flow analysis (work-stream 2, to 2030) estimates future annual investment, then estimates present values (total discounted values from the period 2012-2030) using a 10% discount rate. As highlighted above, the analysis for hydro-electricity does not estimate damage costs, but instead uses the adaptation cost (the changes in system capacity) as a proxy. For this reason, the system modelling for hydro-electricity plant (work-stream 3, to 2050) also estimates present values, again with a 10% internal discount rate used, with a 50 year economic life-time assumed for hydro-plants. The 10% discount rate used in the study is in line with the rate used for the power sector and, in general, for the evaluation of public sector projects in the country.

For the presentation of future economic costs in work-stream 3 for agriculture and water-induced disasters, results are presented as damage costs (economic costs) in terms of constant prices for the future time periods (i.e. the 2020s, 2050s and 2080s) without any adjustments or discounting. The results are presented in this way to facilitate direct comparison over time and between sectors. They are presented as an equivalent % of current GDP, to allow comparison against the costs of current climate variability. It is stressed that for subsequent analysis in adaptation appraisal, these future values would need to be discounted as part of a cost-benefit analysis framework.

For the agricultural and water-induced disaster sections, static assumptions have been applied for underlying trends (e.g. agricultural productivity improvements, rising population, rising assets at risk). However, discussion is included on the potential influence of these changes to the results. For the analysis of hydro-electricity generation, the system modelling does take account of future changes in demand and sector projections for additional capacity up to 2050.

The analysis has used a series of specific climate model outputs for the assessments. However, reflecting the high uncertainty associated with future climate change, a consideration of climate model uncertainty and the influence on the results has been made in each case. It is highlighted that the sensitivity analysis only considers climate uncertainty. Other sources of uncertainty are relevant (e.g. impacts, economic values) and are highlighted for future research.

3.8. Stakeholder Engagement and Capacity Building Activities

In addition to the technical analysis, the project has had wider objectives of stakeholder consultation and capacity building in Nepal. The focus on stakeholder engagement and consultation ensures ownership of the project outputs, and ensures the integrity of the national context. The focus on capacity building seeks to ensure the project has a lasting legacy. To ensure the delivery of these objectives, a consultation and capacity building plan was developed during the inception phase of the project. These activities are described below.

The transfer of knowledge and skills has been an integral and continuous part of this project for two main reasons: (i) the participation of a wide range of stakeholders (including government staff, thematic experts, academia, the private sector and civil society) and their engagement in some of the analysis, which also ensured that the study was truly within the local context, and (ii) because this study was a collaborative effort of Nepalese and international partners working together. To achieve this, the project undertook a series of activities to engage stakeholders, including government and technical consultation.

To ensure capacity building of local researchers, practitioners and government officials for carrying out and using economic impacts of climate change assessments, all tasks were undertaken by local and international teams working together, and involved discussion with local experts, partners and Government officials. Training workshops on climate change impacts and adaptation were held with researchers and government officials, on the approaches and methods for costing.

In order to build capacity across departments, and to provide on-going input, engagement and guidance to the study, a Government Steering Committee was formed at the outset of the study. The project reported to this steering committee at key points of the study: at commencement; at the end of the inception phase to present the methods proposed; and towards the end of the study to present the draft findings.

The study undertook a series of stakeholder consultations, and discussions during each phase of the project to ensure that stakeholders had the opportunity to discuss the work-plan and results, at each stage. National workshops on the project were held at the beginning of the inception phase, at the end of the inception phase, and at the end of the implementation phase, to seek inputs from a wide group of stakeholders.

In May 2012, shortly after the study commenced, the international and national team came together for an early knowledge transfer workshop, to discuss the proposed approaches and methods, as well as to exchange information on the availability of data, local experience using various models, and feasibility of the planned analysis. During the summer of 2012, a number of technical meetings were held to discuss the project, with local Nepali experts from the water and agricultural thematic working groups of the NAPA process. These groups included experts from relevant government departments and research institutes, academia, and civil society. In addition to thematic experts, the groups also included key cross-cutting experts. Through an inclusive and participatory consultation process, these thematic groups provided input on selection of sub-sectors (in the initial phase of the study), provided relevant data and information to the study team, and provided technical comments and inputs on the reports.

In September 2012, a one day Joint Consultation Workshop was held, with relevant Government officials (as agreed by the Steering Committee), and other institutions/organisations conducting related analysis to discuss the approaches and methods proposed in the inception report and implementation plan. Following this, in October 2012, a consultation meeting was held with the Steering Committee and relevant government officials to review the findings of the inception report, and to discuss and approve the methods, models and approaches to be applied during the implementation phase.

In late 2012, a climate change needs assessment survey was designed and carried out. This identified key requirements and interest areas for training in Government. Following the analysis of the needs-assessment, a major training session was designed and held for Government officials. This was held in January 2013, with a 3-day training session held to build the capacity of government officials on climate change (from science to negotiations), with specific training on the methodology and approaches to assess the economic impacts of climate change, and how to use this information for adaptation strategies and wider planning. The sessions, which combined presentations with group work and discussions, were conducted by local and international experts and covered the technical aspects of climate science, climate modeling, climate impacts, vulnerability and uncertainty in impact assessments, the differentiated impacts of climate change, near term costs and investments and financial flow assessments, climate risk screening, climate policy, the economics of climate change and adaptation economics, adaptation finance, loss and damage and potential benefits from climate change, as well as climate diplomacy. In total, there were twenty participants representing different Ministries, Government departments and Civil Society groups[4].

To complete the cycle of capacity building activities, in 2014, the results from the study analysis, as well as the data sets and final models were transferred to the Government of Nepal, together with briefing material about the study. This enhanced capacity of government officials and other stakeholders, will enable the Government to conduct further assessments of the impacts of climate change on other important economic sectors, with the support of the national team.

[4] Training participants represented the Minsitry of Science, Technology and Enviornment (MoSTE), the Minstry of Forest and Soil Conservation (MoFSC), the Ministry of Agriculture Development (MoAD), the Department of Water Induced Disaster Prevention (DWIDP), the Department of Hydrology and Metereology (DHM), the National Planning Commission (NPC), the Nepal Agricultural Research Council (NARC), the Nepal Academy of Science and Technology (NAST), Clean Energy Nepal (CEN), the Association for the Development of Environment and People in Transition (ADAPT-Nepal), Tribhuvan University (TU), Kathmandu University (KU), the NGO-Federation, the Integrated Development Society (IDS) Nepal and Practical Action Consulting.

4 Impacts of Current Climate Variability (Work-stream 1)

Key Summary Points:

- The first work-stream has assessed the current climate of Nepal and the impacts and economic costs of existing climate variability. Nepal has an extremely varied and complex climate, driven by the contrasting terrain and large elevation differences. Nepal also experiences complex seasonal weather patterns, which are heavily influenced by the Himalaya and the annual monsoon.
- Analysis of recent observational data shows that the climate of Nepal is already changing. Temperatures have risen significantly over recent decades. There have also been changes in precipitation, including heavy rainfall extremes, though the trends are more complex and show wide variations across seasons and regions. There have also been changes in glaciers, some of which are retreating and thinning.
- Water-induced disasters, notably floods associated with the monsoon rains, are frequent and lead to loss of life and major property and infrastructure damages. The study has assessed the information on events over the last thirty years, and estimated the economic costs of these, including the health and welfare related impacts. The estimated total direct annual economic cost of water-induced disasters is US$270 million/year on average, equivalent to 1.5% of current GDP. However, there is wide variability across years and in exceptional years, the costs of floods can rise to 5 % of GDP equivalent.
- Nepalese agriculture is predominantly small-scale farming, much of which is heavily dependent on natural rainfall. As a result, rainfall and other climatic factors are critical to yields, and there are large annual variations in production. The sector is also affected by climate extremes, including droughts as well as floods. The economic costs of major droughts, such as the ones that occurred in 2006 and 2009, are large, with direct cost from lost agricultural output estimated at 1.9% and 0.4% of current GDP, respectively. Again, the full economic costs of these events are higher, due to the health and welfare losses associated with food insecurity. Nepalese agriculture in the hills and mountains is also affected by soil erosion, due to the steep gradients and intense monsoon rainfall, which reduces soil fertility, and ultimately, agricultural productivity.
- Current climate variability also affects hydro-electricity generation. The seasonal variation in rainfall means that a number of run-of-river hydro plants do not operate at the desired or planned capacity during the driest months of the year (January to April). This leads to planned supply interruptions (often referred to as ‘load shedding’ in Nepal). These power interruptions have a high economic impact. These impacts are highest in low rainfall years, where they can also reduce storage reservoir recharge (which occurs during the monsoon). An analysis of the impact of climate variability on electricity production (and the impact of planned interruptions) indicates economic costs could be equivalent to 0.1% of GDP per year on average, and 0.3% in very dry years. Hydro-electric plants are also subject to the risks of floods including, for some, the risk of Glacial Lake Outburst Floods (GLOFs). There was the loss of a multi-million dollar hydro-power facility in 1985 due to a GLOF event.

- The overall analysis shows that direct economic cost of current climate variability in Nepal is very high and extreme events can affect the livelihoods of hundreds of thousands of people in extreme years. They also have high direct economic costs, estimated at 1.5% to 2% of current GDP equivalent as an annual average, and as high as 5% for extreme years. These economic costs are dominated by water-induced disasters, though major drought years are also important. These costs exclude indirect costs and macro-economic costs, thus they are a potential underestimate: including these wider costs would likely increase total costs by at least 25% to 100%.
- A key conclusion is that Nepal is not adequately adapted to the current climate and has a high existing adaptation deficit. Addressing this deficit is a priority for early low-and no-regret adaptation.
- The analysis also shows a high level of spatial variation in impacts across the country, reflecting differences in climatic and agro-ecological zones. There are also different impacts between different groups of society, notably related to gender and poverty. To explore these issues - and community based perceptions of current climate variability and trends – three local case studies were undertaken.

4.1. The Current Climate of Nepal

Nepal's climate is extremely complex and varied. This is in part due to its topography (Figure 4.1). Within a few hundred kilometres, the elevation rises from the flat Terai plains - with a low point only 70 metres above sea level - to the top of Mount Everest (8,848 metres), and this drives strong temperature gradients across the country (Figure 4.2) as temperature falls on average with elevation level. Reflecting this, the lowland regions of Nepal have a warm and humid sub-tropical climate, while the high mountainous regions are cold, remaining well below zero in the winter (PA, 2009). The highest temperatures occur during the pre-monsoon period.

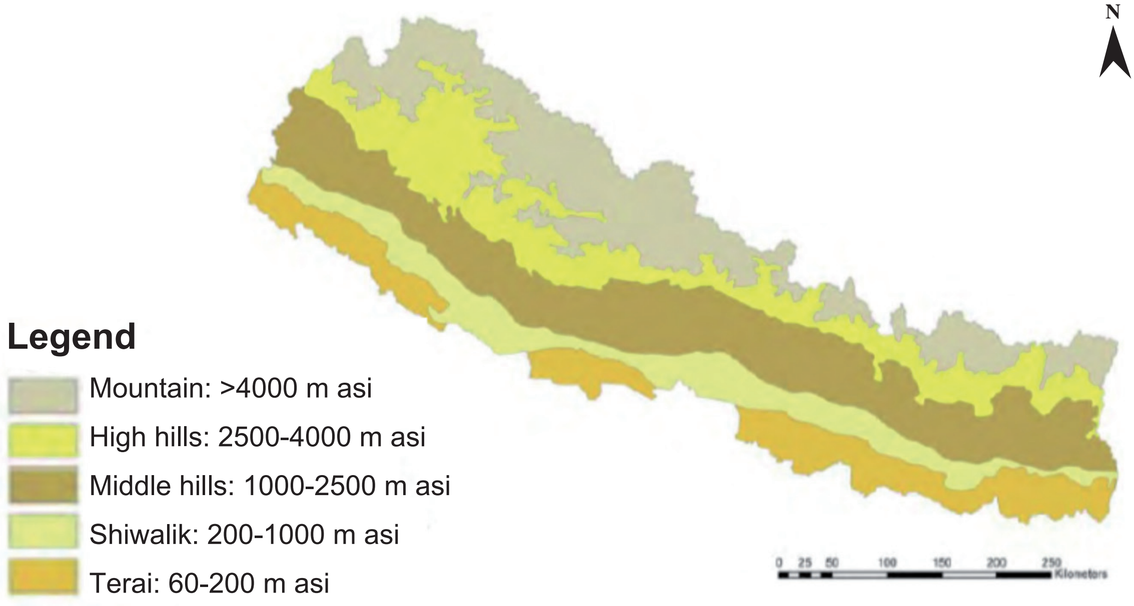


Figure 4.1. Elevation Gradient across Nepal

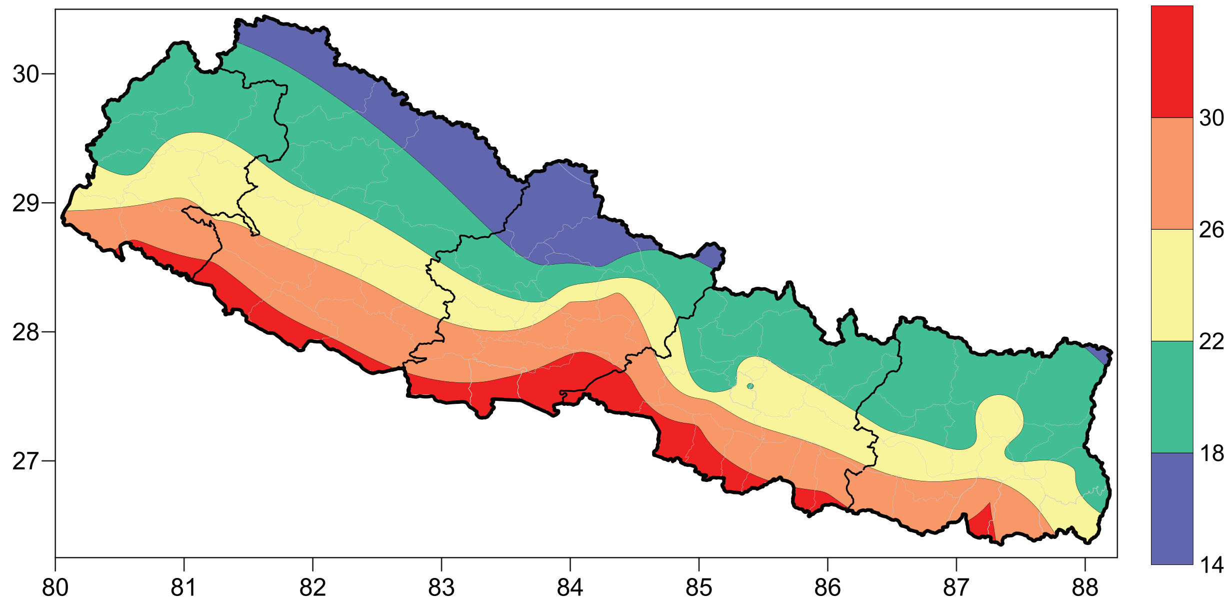


Figure 4.2. Spatial variation of mean maximum temperature across Nepal (Key =°C, axis = Latitude, Longitude)

Source: PA, 2009.

Nepal also experiences complex seasonal weather patterns, which are heavily influenced by the Himalaya, and vary by region. The terrain and topography – notably the large mountain systems – have a major impact on rainfall patterns. Average annual rainfall is approximately 1800 mm (GON, 2010), but rainfall is dominated by the monsoon rains, from June to August/September. The monsoon rain is most abundant in the east and gradually declines as it moves towards the west (GON, 2010: PA, 2009). High extreme rainfall is a major source of floods and landslides, as well as soil erosion and sedimentation transfer. In addition, there is also high variability in annual and seasonal rainfall between years (Baidya et al. 2007; PA, 2009), which is important in subsequent impacts across other sectors.

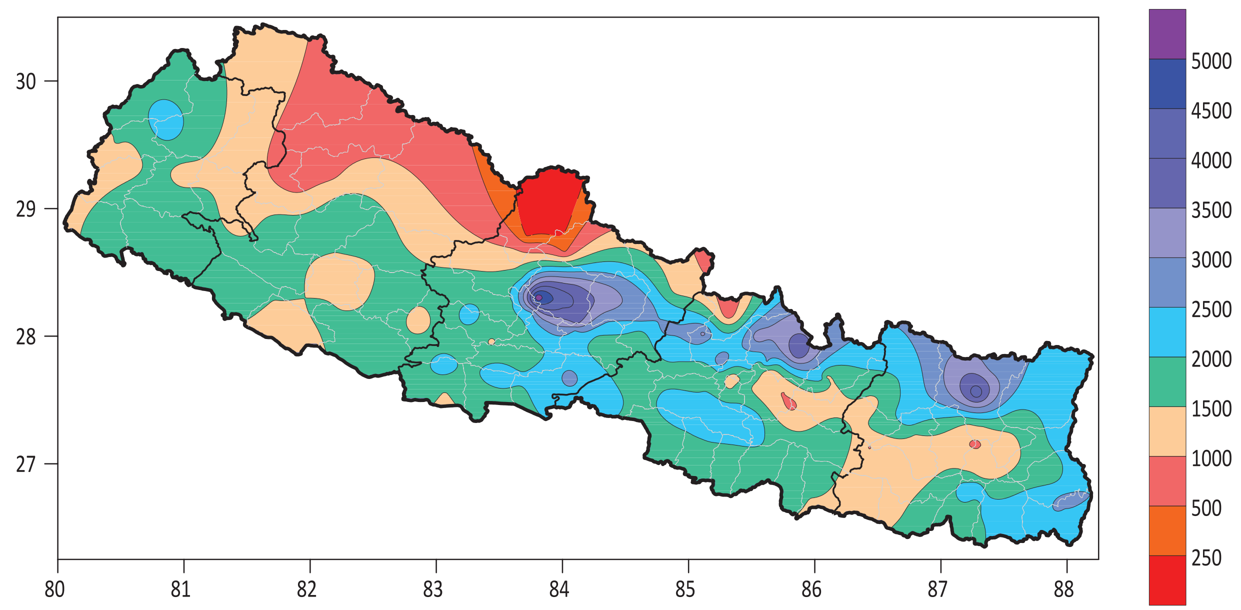


Figure 4.3. Annual mean rainfall (key = mm, axis = Latitude, Longitude)

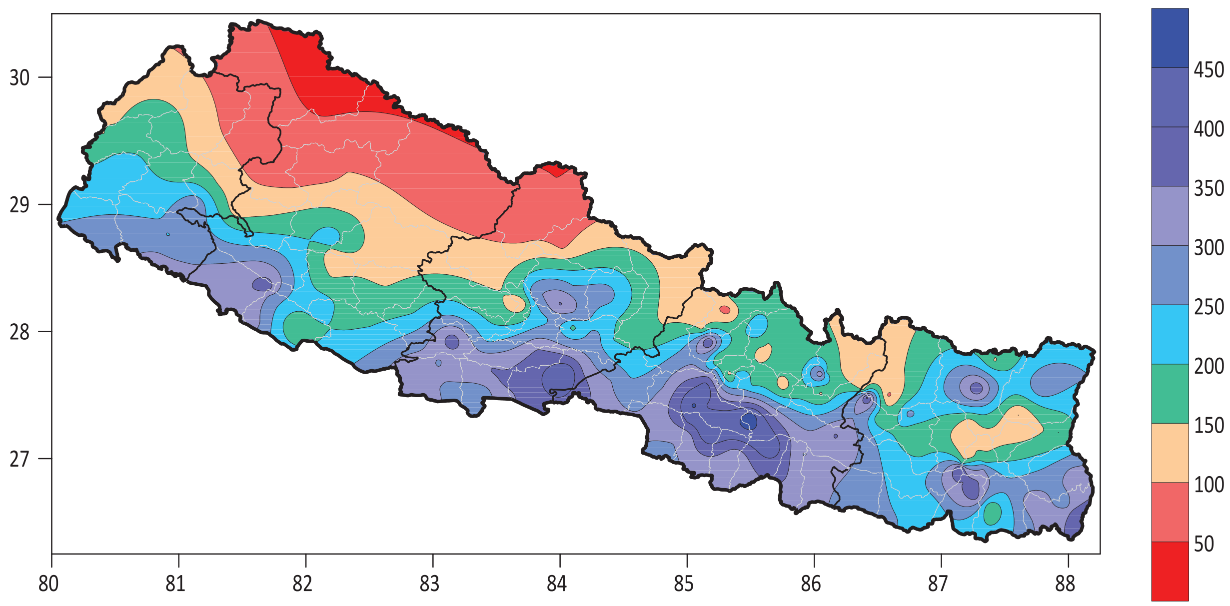


Figure 4.4. Twenty-Four hours highest rainfall (key = mm, axis = Latitude, Longitude)

Source: PA (2009).

4.2. Emerging Climate Trends

When looking towards early impacts of climate change, a critical question is on emerging trends, i.e. what changes are occurring already, as these provide useful information on how climate change might evolve over the next decade or so. The study has reviewed the recent trends looking at observational data, including recent trend reviews by Shrestha et al. (1999); McSweeney et al.; Baidya et al. (2007); Saraju et al. (2008); PA (2009) and GoN (2010).

The NAPA (GON, 2010), based on a detailed analysis (Practical Action, 2009) over a period of 30 years (1976 to 2005) reported a trend of observed warming for Nepal of approximately 0.4°C to 0.6°C per decade, with spatial differences across the country (shown in Figure 4.5 below). This is significantly higher than the global average trends, which are closer to 0.1°C per decade (IPCC, 2013). Both maximum and mean temperatures are rising.

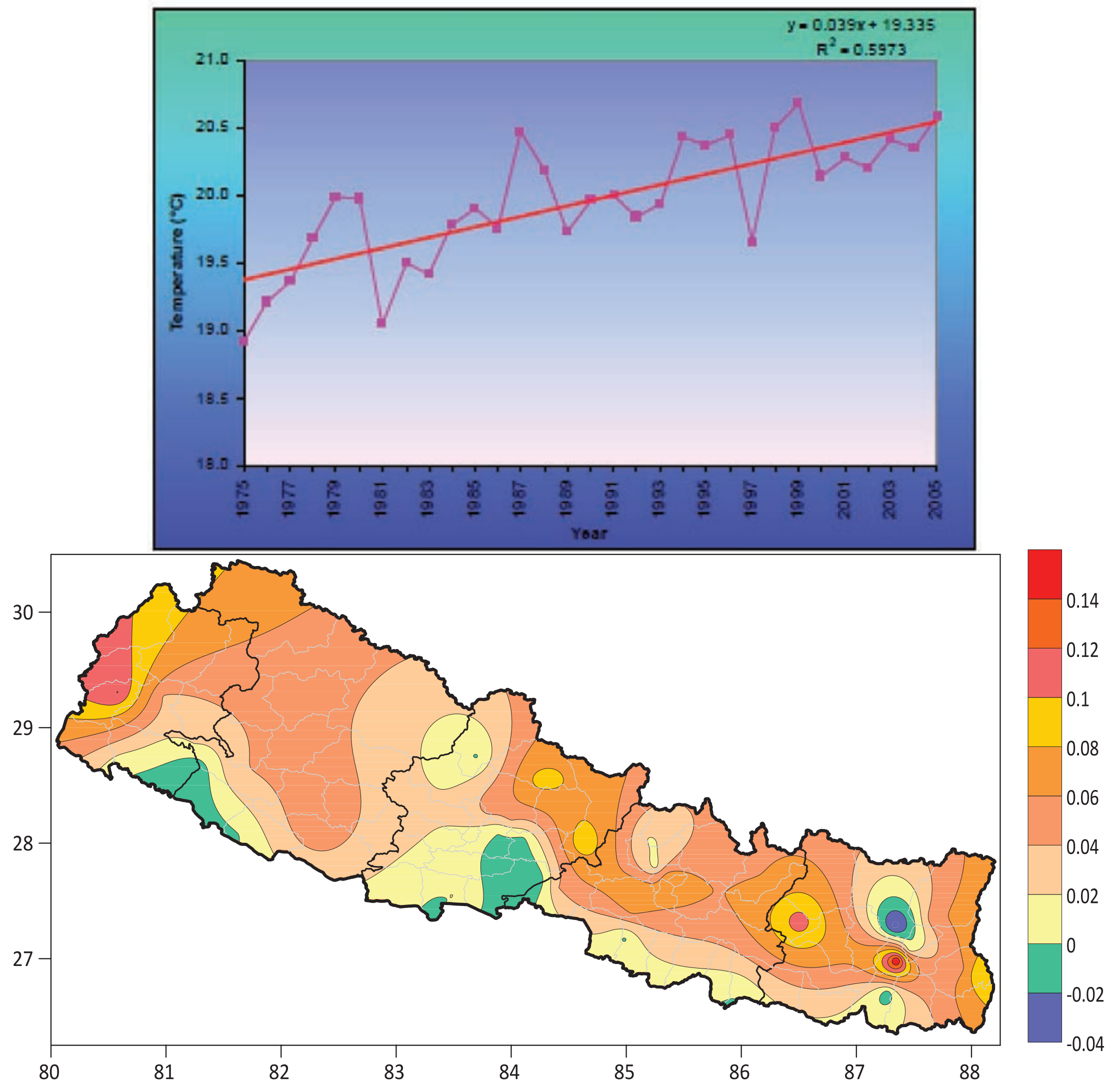


Figure 4.5. Top Annual mean temperature trend Nepal (Baidya et al., 2007). Bottom. Spatial pattern (key °C/year, axis Longitude, Latitude)

Source PA, 2009.

Further increases in temperature from climate change are anticipated over the next decade or two, (e.g. the trend shown in Figure 4.5 is expected to continue). It is noted that any increase in temperature needs to be considered against the existing temperature gradients in Nepal in respect to altitude (e.g. from the low, hot plains to the high, cold mountains), which means that very different impacts will occur even if similar levels of absolute warming occur.

Regarding rainfall trends, the situation is more unclear. The NAPA reported that precipitation data does not show any general nationwide trend (though the UNDP country profile (McSweeney et al.) reported a trend of decreasing annual precipitation). However there are a number of regional precipitation trends and the NAPA reports that annual precipitation data shows a general decline in pre-monsoon precipitation in far-and mid-western Nepal, with a few pockets of declining rainfall in the western, central and eastern regions. Other studies (Baidya et al. 2007; Practical Action, 2009) report a change in precipitation over time during the different seasons with some regions showing increases and others showing decreases, as shown in Figures 4.6 and 4.7 below. Saraju et al. (2008) found an increasing trend in the number of extreme precipitation days at the majority of the stations (but particularly for stations below 1500 metres) and highlighted the implications for landslides, flash floods and inundation.

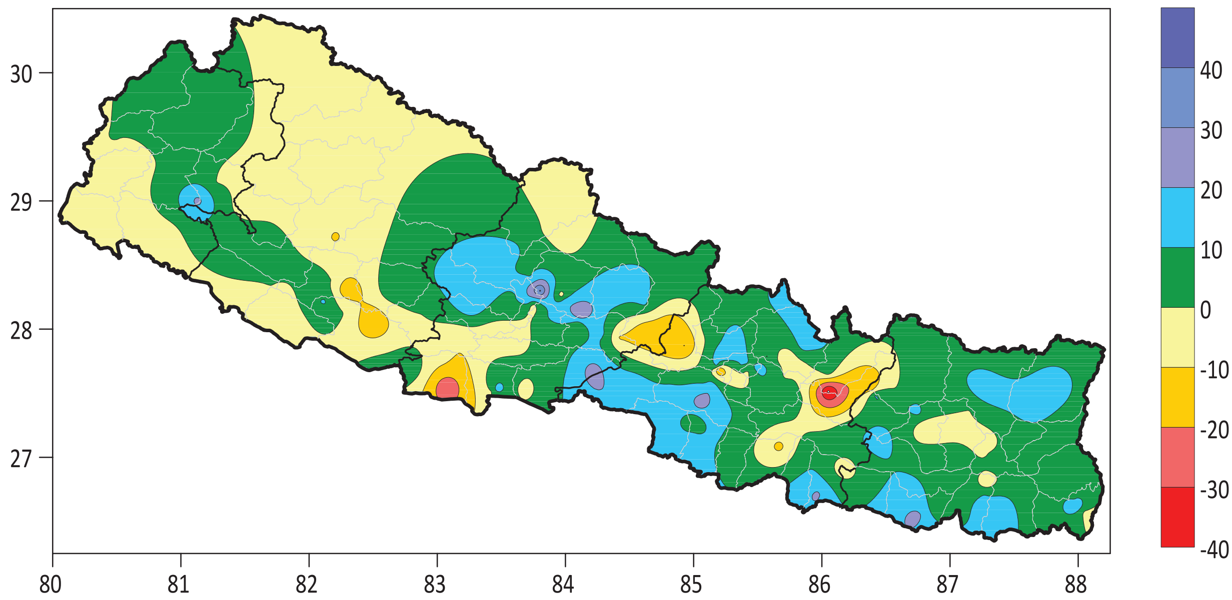


Figure 4.6. Annual rainfall trend (Key = mm/year; Axis = Long., Lat.).

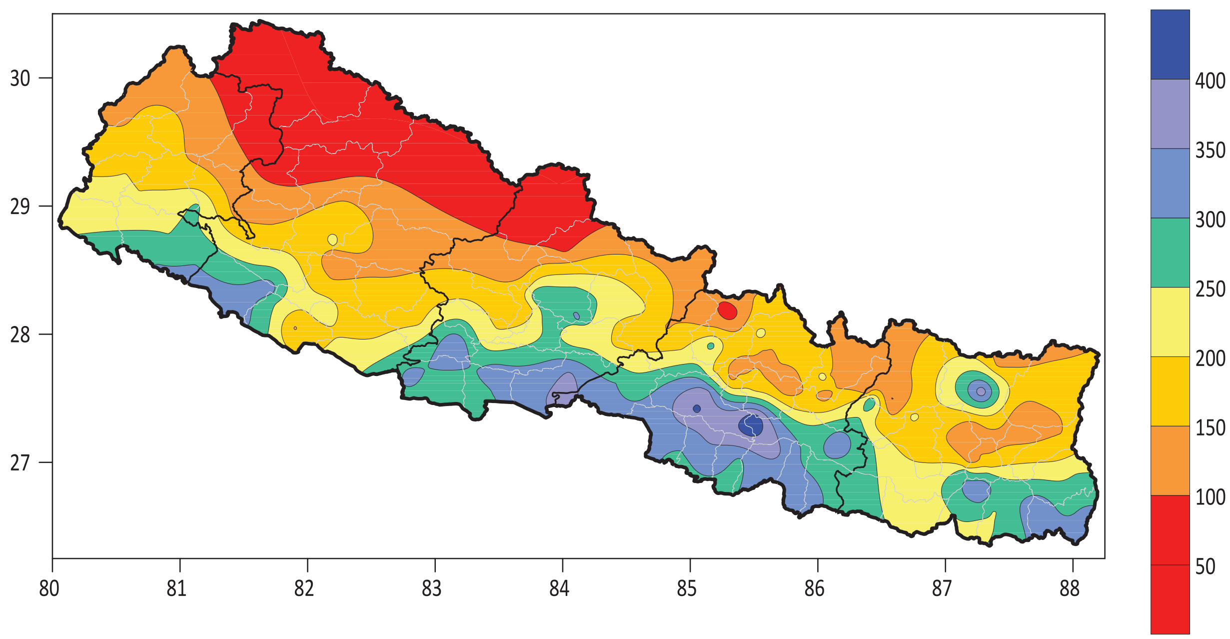


Figure 4.7. Extreme rainfall 25 yr return trend (Key = mm/year; Axis = Long., Lat.)

Source: PA, 2009

The analysis of precipitation is further complicated because of the large variation across the country and the high inter-annual and inter-decadal variability. The NAPA observes that Nepal's inter-annual variation of rainfall, particularly monsoon precipitation, is so large that observed trends are very uncertain and could be a part of the natural cycle.

A key conclusion is that the consideration of emerging trends needs to factor in the very long cycles in the climate (i.e. decadal), and may need to focus on trends at the regional/seasonal level. It is stressed that any new analysis is unlikely to resolve emerging trends with certainty, though enhancing the monitoring network is important to build a comprehensive data set for future analysis.

While the changes in temperature and precipitation are the most obvious changes, there are a wide range of other climatic parameters that are changing, which also affect the bio-physical environment. Some of the most important changes relate to the cryosphere. The recent IPCC (2013) summary for policy makers (from Working Group I) reports that glaciers have mostly continued to shrink worldwide. The changes in the Himalaya are, however, very complex, with little consistent pattern of increased rates, further compounded by the inaccessibility of the region and lack of documentation. ICIMOD (Singh et al. 2011) reports that in general, glaciers on the central and eastern Himalayas are shrinking, while changes in the western Himalayas are more uncertain. In Nepal, there are observational records that some glaciers are retreating – some quite quickly – and some glaciers are thinning. These changes are important in relation to the potential changes they lead to in glacial melt-water contributions to river flows, and also in the number and growth of glacial lakes, and the subsequent risks of glacial lake outburst floods (GLOFs). ICIMOD is also tracking the extent and formation of glaciers and glacial lakes. Altogether 2,315 glacial lakes have been identified in Nepal and about 20 of these have been identified as being potentially dangerous at present (GFDRR, 2012).

4.3. Impacts and Costs of Current Climate Variability (Work-stream 1)

As highlighted earlier, a large proportion of the GDP in Nepal and the livelihoods of its people fall within climate sensitive activities. These impacts are particularly high in the sectors of interest to this study, because of the high levels of annual and seasonal climate variability, and also extreme events (floods and droughts).

Work-stream 1 of the study has assessed the impacts of current climate variability in Nepal, and sought to estimate the current economic costs in the agricultural, hydro-electricity and water-induced disaster sectors. This section summarises the results of the analysis.

Water-Induced Disasters

Water-induced disasters are a major natural hazard in Nepal. Floods are the major climate related hazard in the country (GoN, 2010), particularly during the monsoon season, though landslides and drought are also significant. Previous work in the NAPA (GoN, 2010) has mapped the vulnerability of water-induced disasters. It shows the differing distribution of risks across the country, as shown in Figure 4.8 below. The highest vulnerability to floods is in the lower plains of the Terai, while the high vulnerability to landslides is in the hills and high mountains.

A number of impacts arise from these water-induced disasters. First, there is direct damage to, and loss of assets such as buildings and infrastructure, agricultural crops and livestock. Second, there are direct effects that occur in non-market sectors, e.g. the loss of life, injury, impacts on well-being, etc. Finally, there is a set of indirect effects that arise, particularly from major floods, which are associated with lost industrial production, electricity outages, transport disruption, and may have wider effects across the economy. These may lead to impacts that arise in areas outside the immediate flood area, and may even impact at the macro-economic scale from negative feedbacks on the wider economy. It is also to be noted that there may also be long-term indirect non-market effects, e.g. the health impacts that may arise following a flood (e.g. from disease outbreak) or the long-term increased vulnerability of survivors.

A number of data sources exist on the impacts of historical floods. The Emergency Disaster Database (EM-DAT, 2013) reports that the 2009 flood had a cost of US$60 million, and earlier floods in 1987 and 1993 have reported costs of US$727 million and US$200 million respectively. The SPCR Final Document (GoN: SPCR, 2010) carried out an extensive analysis of historic risks across different parts of the country, producing maps of the geographical pattern of historical events, including the loss of life and people affected by different types of climate hazards (floods, landslide, etc.) and property losses (with some splits in terms of area and over time). It reported a rising trend of property loss from floods over the last thirty years.

Given the importance of these events, a number of previous and ongoing studies have investigated these issues. These are summarised in the box below.

Flood Vulnerability Map (Terai).

Previous and ongoing studies

There have been a number of studies that have built up a more detailed bottom-up analysis of the magnitude, frequency and impacts of water-induced disasters in Nepal. The Nepal Climate Vulnerability Study Team (NCVST) study (NCVST, 2009) considered eight signature events of the recent past[5] and looked at the consequences of these events on an average Nepali household, using past studies, field observations and bottom-upsurveys to estimate the burden per household. There has also been some detailed case study work (NDRI and UNESCO-ICHARM, 2012) on flood inundation in Lower West Rapti Basin (see later case study). As part of this study, village surveys were undertaken to assess the degree of flood impact, as well as agricultural losses, health effects and disruption. This allowed estimates of direct damage, agricultural impacts and business damage, with the derivation of a depth damage function.

There is also major on-going work on the risks of Nepal's major hazards at national and sub-national level being undertaken for the Government with the assistance of the World Bank's Global Facility for Disaster Reduction and Recovery (GFDRR), including hazard assessment and hazard mapping for floods and droughts. This has developed flood hazard maps for seven of the most frequent flood prone river basins- Rapti, Babai, Bagmati, Narayani, Tinau, Kankai and Kamala. The mapping presents the basins' flood severity in terms of inundation depth and area with respect to the return period of 10 years, 25 years, 50 years and 100 years. Similarly, drought mapping assessments have been carried out across the four seasons- winter, pre-monsoon, monsoon and post-monsoon, with hazards classified into moderate, severe and extreme conditions. GFDRR also funded a study which compiled hazard exposure to present a national 'baseline' in the country, presented in a series of detailed hazard risk maps (GoN/GFDRR), which includes economic modelling using the CATSIM model. These aids have been complemented by detailed assessments of different risk exposure, hazard by hazard, which lead to initial recommendations for risk-reducing interventions in key at-risk areas. The PPCR is also in the process of initiating a major exercise to improve hydro-meteorological systems. It is undertaking detailed sub-basin modelling and hazard and exposure response mapping, and planning to use these data for integrated water resources management.

[5] The 1998 Rohini River and other Terai floods, the 2008 Koshi embankment breach, the 2008 Flooding in Far-West Nepal, the 1993 Mid-mountain cloudbursts and floods, the Recent glacial lake outburst floods, the 2008/2009 Winter drought, the 2009 forest fires and the 2009 diarrhoea epidemic in the mid-western hills.

Landslide vulnerability map (hill and mountain zone)

Figure 4.8. Vulnerability maps for Nepal

Source: NAPA, GoN (2010).

This study has avoided duplicating these hazard-mapping studies. Instead it has focused on trying to assess the full economic costs of these events. The analysis has started at the national level, building on the existing data collected by DWIDP for floods and landslides. This data was validated with the MoE officials and used un-adjusted, though it was noted that records for a small number of districts were incomplete. The number of fatalities and losses from water-induced disasters are presented below. The high frequency of these events can be seen in Figure 4.9 below. The DWIDP data report an average annual number of fatalities of 283/year, 8000 homes destroyed/year and 29,000 families affected/year. SPCR (2010) reports higher and rising property damage costs over the two decades, compared to the previous two decades. However, these increases are likely to be due to socio-economic change, and the large increase in population, buildings, infrastructure, changing settlement patterns, deforestation and land-use change, rather than due to changes in climate and natural hazards.

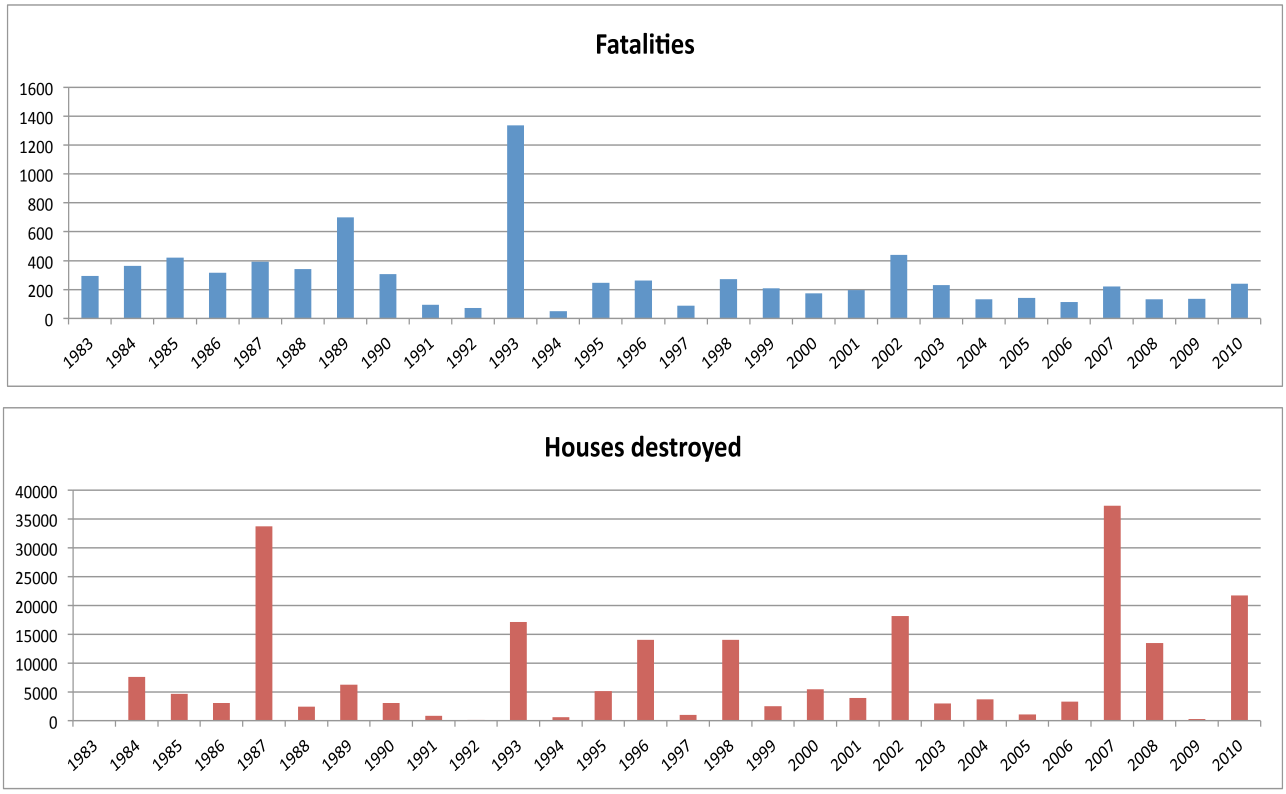


Figure 4.9. Fatalities and Houses Destroyed

Source: DWIDP.

This study has used the DWIDP data sets and assessed the economic costs of water-induced disaster events. Data on losses in the database are reported in the year of the event, rather than updated to current prices (personal communication with DWIDP). The data has been first updated to current prices, to adjust the DWIDP values, and then converted using the NPR/US$ value for the year in question, to express in US$2013. The values using GDP deflators are shown in Figure 4.10 below. However, this only includes the direct damages (losses). It does not include the full economic costs from the impacts on health and disruption. Following the method set out in Chapter 3, the mortality (using the value of a prevented fatality (VPF) - also known as the Value of Statistical Life (VSL), injuries and wider welfare impacts have also been estimated and valued[6].

When both direct damage and health impacts are included, the total direct annual costs average US$270 million/year (2013 prices) equivalent to 1.5% of current GDP. The costs are dominated by property loss (at US$187 million per year on average) but damages to public infrastructure are very large in certain years (see Figure 4.10 below). The health and welfare impacts are smaller, but still important. It is noted that the number of injuries is likely to be under-reported, as the data reports the number of deaths are greater than injuries.

There is also very wide variability across years, for example, the total cost in 1993 is over 80 times that of 1992. In exceptional years, the costs rise to as large as 5% of GDP equivalent. Note that the relative importance of floods versus landslides varies by year, though major flood events dominate the high loss years shown below.

[6] For the figure, a central value for mortality valuation used was $23035 (2013 prices). Multipliers of 0.05 and 9.2 have been applied to give low and high uncertainty bounds, respectively.

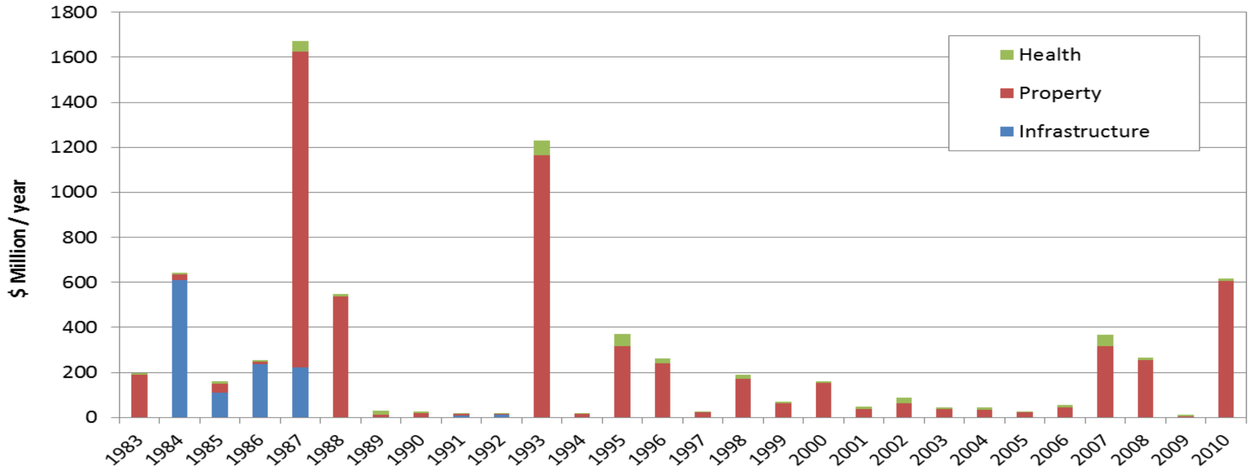


Figure 4.10. Economic Costs (Aggregate) of Water-Induced Disasters (Flood& Landslide) in Nepal: 1983 – 2010, Split by Infrastructure, Property and Health Damages. Current 2013 prices

Source: Project Team, based on DWIDP (2012).

It should be noted that even these monetary estimates do not include valuation of the full welfare impacts from households affected, and therefore, are under-estimates of the overall welfare costs. These welfare impacts include a wide range of possible effects resulting from people requiring immediate assistance, to the post-flood period and a range of direct and indirect impacts. They also exclude the damages from floods on natural ecosystems, and ecosystem services.

Importantly, the results only consider the direct economic costs (tangible and intangible) of these events. They do not include the indirect effects and the overall macro-economic costs. Indirect costs occur as a consequence of initial flood impacts and damages, e.g. business disruption and lost wages. Macroeconomic impacts include the aggregate impacts on economic variables such as GDP, consumption and inflation due to the effects of disasters, as well as the shift of government resources to relief and reconstruction purposes. Assessing these additional impacts requires linked models (see discussion in Chapter 3). The review found no existing example of such application in Nepal, though the GFDRR Nepal Hazard Assessment (GFDRR, 2012) is developing the IIASA CATSIM model (to look at major effects on capital assets/stocks and economic variables) and Input-Output (I-O) analysis in the form of a Social Accounting Matrix (SAM) to consider the inter-sectoral linkages to assess how disasters ripple through the economy.

There is, however, evidence from other countries that have undertaken such assessments. Hallegatte et al. (2007), using an I-O model reports that the full macro-economic costs of natural catastrophes could be 25% more than direct costs alone, but can rise to be twice as large as direct losses for very major events. Wilbanks et al. (2007) note that, following large events, as much as a quarter of national output is lost over a number of subsequent years, and highlight a particular issue when large events appear more frequently, in that the economy does not fully recover before the next event occurs, which leads to long-term growth reductions.

This indicates that the total costs of water-induced disasters (including indirect and macro-economic costs) are likely to be 25% to 100% greater than the direct costs (i.e. equivalent to 1.0% to 1.6% of GDP on average). It is highlighted that total losses are likely to be greater in the major event years (e.g. 1987 or 1993 type events in Nepal).

In addition to the floods from monsoon rains, Nepal also experiences Glacial Lakes Outburst Floods (GLOFs). These events are much more infrequent but have potentially catastrophic consequences. The distribution of GLOF risks is obviously different from the majority of other floods, with vulnerability concentrated downstream of glaciers, as shown in Figure 4.11. Around 14 GLOFs have been reported between 1935 and 1991 in Nepal (ICIMOD, 2007).

Matambo and Shrestha (2011) report that since 1964, seven major documented glacial lake outburst floods have occurred in the country. The most significant was the outburst of the Dig Tsho Glacial Lake in 1985, which damaged a recently constructed hydroelectric power plant, 14 bridges, 30 houses and farmland worth four million dollars, and led to five fatalities.

While the damage and loss of life from these events are locally important, the costs are low compared to annual flood impacts reported above, because of the low frequency of occurrence of GLOF events and also because of their more limited geographical extent. As an example, the 1985 GLOF led to the death of five people: this compares to the fatalities from floods more generally, which over the period from 1985, have led to 285 deaths/year on average. Similarly Matambo and Shrestha (2011) report that the value of the elements exposed to potential glacial lake outburst floods is estimated between US$2 million and US$9 million. This estimate may be conservative, but it is still very low compared to the annual flood damages reported above. Therefore, even though GLOFs remain an important risk, especially in the context of a large glacial lake outburst, their annualised contribution to current climate-related natural disasters (and the adaptation deficit) is low compared to the very large impacts from routine flooding in Nepal.

Figure 4.11. GLOF Vulnerability Map

Source: NAPA, GoN (2010).

Agriculture

Nepalese agriculture is predominantly small-scale and much of it is heavily dependent on natural rainfall. As a result, rainfall and other climatic factors are critical to crop yields, and there are strong annual variations in production and growth rates due to these factors (WFP, 2009; Sthapit and Shrestha, 2008; GoN and WFP, 2011). Sherchand et al. (2007) report that 70% of the performance of crop production is explained by climatic variability linked with the temporal weather conditions. The sector is also affected by extremes, including droughts and other extreme weather events (heat stress, hot winds, cold waves, hailstones and snowfall), as well as floods.

The study has investigated the current impacts and economic costs of climate, variability and extremes on the agricultural sector (noting the effects of water-induced disasters are captured above).

Droughts are complex phenomena that are typically classified in terms of meteorological, hydrological, agricultural and socioeconomic droughts, and there are many indicators associated with each. The impacts of major droughts are most obviously manifested through crop and livestock losses, and effects on production. Drought events can have much wider economic impacts, associated with fatalities and impacts on health, with the effects on local people and the additional time spent searching for water or food, losses in hydro-power generation and even lost industrial production.

At the aggregate level, it is clear that droughts lead to major reductions in agricultural production. However, the patterns of droughts are very irregular, and therefore very different to floods. There area number of major droughts on record. The EM-DAT database (EM-DAT, 2013) reports that the drought in 1972 affected 90000 people and had an estimated cost of US$10 million and that the drought of 1979 affected 3.5 million people. There have been a number of relatively large-scale events over recent years, with major droughts in 2006, 2008/9 and 2009/10. The UN WFP (2009) reports that 2009 winter crop harvests were reduced by 40% (Mountain), 25% (Hill), and 10% (Terai) compared to the previous year due to the dry winter, leading to a national decrease in production of wheat and barley (the two major winter crops) of 14.5% and 17.3%, which led to an annual cereal deficit of 133,000 mt despite an excellent summer crop harvests. The 2009 winter drought came after a severe 2006 winter drought combined with extensive summer flooding (resulting in 225,000 mt grain deficit). Given the context of low stock levels prior to the 2009 poor harvest (down 20 percent compared to 2008) the result was a serious deterioration in food availability, particularly in the most hard hit and isolated regions of the Mid to Far Western Hills and Mountains (UN WFP, 2009). The 2009/2010 drought event is reported to have led to an 11% loss of rice yields, 7% loss in wheat and maize, and resulted in a grain deficit of 400,000 tons (IIED, 2011).

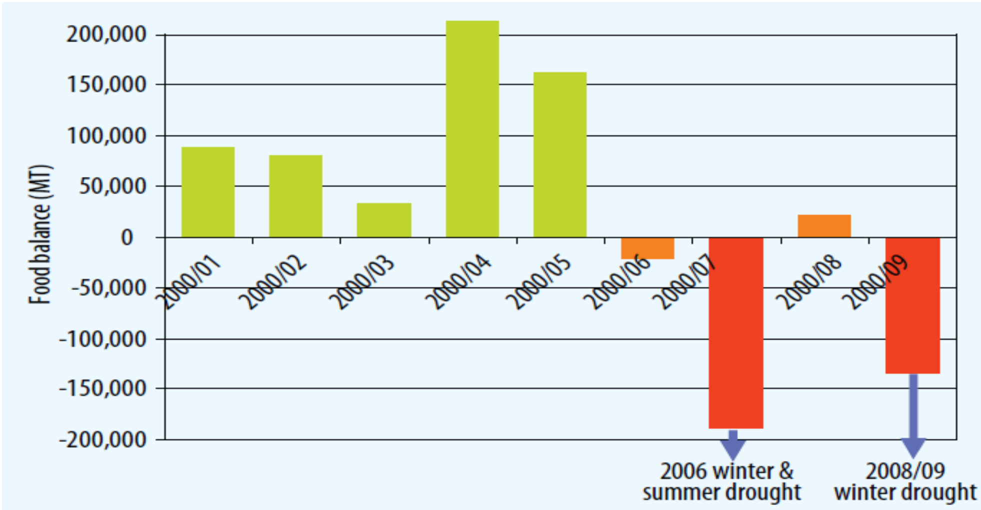


Figure 4.12. Nepal Annual Cereal Production Surplus/Deficit

Source: UN WFP (2009).

These drought events can be regional or localised-and vary across the country, as shown in the NAPA mapping in the drought vulnerability Figure below (4.13). Note also the different geographical pattern to flood and land-slide vulnerability in the maps in the previous sections.

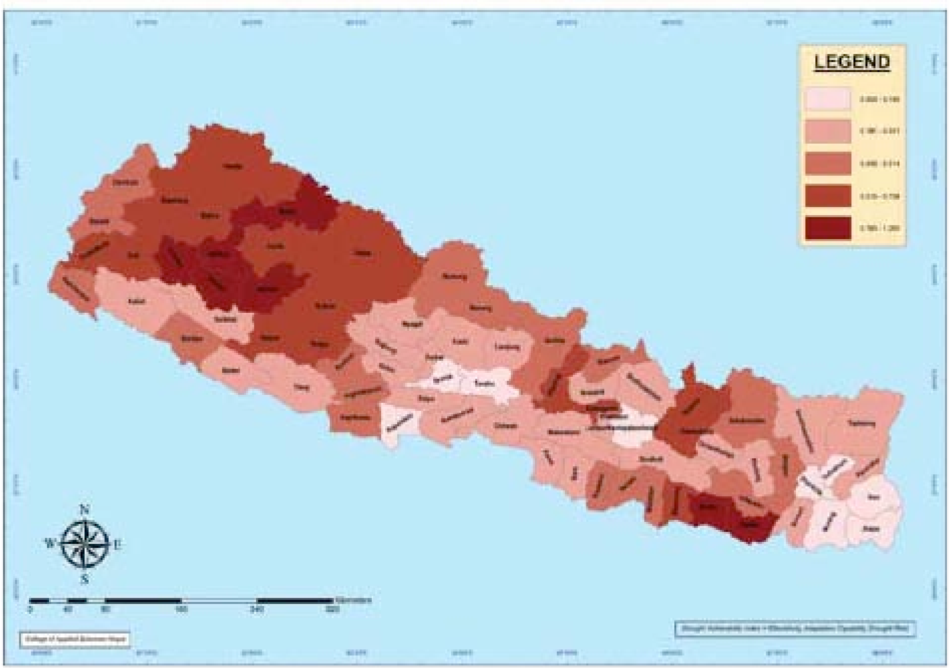


Figure 4.13. Drought Vulnerability Map

Source: NAPA, GoN (2010).

Along with the effects in terms of lost production, major droughts have large welfare costs, especially when they affect large number of people. The EM-DAT International Disaster Database (2013) reports that the 2009 drought affected 303,000 people and the 2006 drought around 200,000 people. Almostone million people were made highly or severely food insecure by the 2006 and 2009 events (UN WFP 2009).

The direct economic cost of these recent droughts can be estimated by valuing the lost agricultural output. In 2006 the drought resulted in an 11% loss of rice yields and a 7% loss in wheat and maize whilst in 2009 there was a loss of wheat and barley yields of 15% and 17%, respectively. The economic costs are presented in Table 4.1 below, using the international market prices presented in Chapter 3. They equate to 1.9% and 0.4% of current GDP for the two events, respectively.

Table 4.1. Drought related agricultural costs in Nepal: Direct economic costs. Current 2013 prices

	Lost production (million tonnes)		Economic cost (US$)	
	2006	2009	2006	2009
Wheat	226,000	110,000	65,148,000	32,040,000
Barley	5,000	-	1,068,000	
Rice	445,000	-	270,204,000	
Maize	-	130,000		33,108,000
Total			336,420,000	65,148,000

It should be noted that these estimates do not capture the indirect costs associated with lost production such as the effects of the resulting lower household incomes on regional economies and the macro-economy. These indirect effects would be expected to exert powerful negative multiplier effects. They also do not include the wider health and welfare effects of food insecurity, wider disruption and indirect costs, and macroeconomic effects. As such, they are likely to under estimate the full economic costs.

In addition to the major events (floods and droughts) above, agricultural production in Nepal varies with temperature and rainfall, and as there is high annual rainfall variability in Nepal, this leads to an additional set of impacts from climate variability. A number of studies have looked at the relationships that link agriculture production to climate in Nepal (GoN, 2004; Sherchand et al., 2007; Malla, 2008; Chapagain, 2011; Sharma and Dahal, 2011; Bastakoti et al., 2011). These identify the high inter-annual variability for rain-fed agriculture, especially associated with important development stages, e.g. the pre-monsoon rains, and winter rainfall for wheat. These effects can be complex, and the timing of variability is critical. Some studies have linked higher maize production to increased water availability during development (pre-monsoon), but also finds that high rainfall is detrimental during maturity and harvesting (Nayava et al., 2010).

There have also been some Ricardian (econometric) studies in Nepal, which consider the long-term productivity of land, and consider different influences on land value or farm net revenues, including climatic differences, using cross-sectional data. Whilst the Ricardian method is often criticised - inter alia - on the basis that it may not be able to capture all the important explanatory variables, it does have the merit of providing a systematic framework within which to examine these relationships. In this regard, Thapa and Joshi (2010) identified existing relationships between net farm income and climate variables, and found these variables have significant impacts on the net farm value per hectare. The study reports that relatively low precipitation and high temperatures during the fall and spring seasons seem to have a positive impact on net farm income. This is because high precipitation during these periods coincides with the harvesting of major crops such as paddy rice and maize (in fall) and wheat (in spring), and thus increases the risk of damaging crop output during harvest. The study also reported that net farm income is likely to be increased by summer precipitation (enhancing productivity of rain-fed crops), but not by summer temperature.

Finally, in addition to the short-term effects of heavy rainfall in the form of floods and agricultural losses, there is also the impact of heavy rainfall on soil erosion. Soil erosion is an inherent characteristic of Nepal's climate and topography. The combined effect of steep and rugged mountain topography and intense monsoon rainfall make the country prone to high soil erosion rates (DSCWM, 2012) and these can be exacerbated by cultivation practices. Soil erosion is an important form of land degradation and the loss of topsoil reduces soil fertility and thus long-term productivity of agricultural land. There is a general relationship of soil erosion with rainfall intensity, soil type and the land gradient (slope), as well as land management, but soil erosion patterns can be heterogeneous, even within a specific watershed, as well difficult to assess.

Soil erosion can be measured in physical terms, as the loss in tonnes/hectare. Gardner and Gerrard (2003) undertook soil erosion surveys on the cultivated rain-fed terraces in the Middle Hills of Nepal and reported that losses ranged from 2.7 to 8.2t/ha in 1993 and up to 12.9t/ha in 1992. While these were perhaps lower than commonly perceived they are still high. In contrast, other studies have found much higher rates in vulnerable regions, such as the Siwalik Hills (Ghimire et al., 2013), which due to the combination of sheet, gully, landslides and stream bank erosion was losing 64t/ha of sediment annually.

The economic costs of soil erosion can be valued using replacement costs (e.g. from the costs that would have to be incurred in order to replace a damaged asset such as the annual marginal costs of fertilizer applications to compensate for the loss of soil nutrients due to erosion) or in terms of loss of productivity (the value of the lost crop production valued at market prices, with future losses discounted by market interest rates), though there are issues with both methods. In the absence of detailed information, it is difficult to estimate the economic costs of soil erosion in Nepal. The broader literature reports that rates as high as these would affect productivity, potentially reducing agricultural GDP by several percent, at least in the cultivated areas of the hills and mountains. It is noted that there will be re-deposition of sediments downstream, including during floods, which will have potential benefits.

Finally, it is noted that the observable shifts in temperature are reported to have already affected the crop calendars and the land suitability of some crops/areas in Nepal. There are reports of changes in sowing or planting dates of crops. Further, lands which were previously suitable to one crop or variety are now gradually becoming unsuitable. There are also anecdotal reports of more irregular rainfall patterns, which are making rice seedling transplantation more difficult and leading farmers to change crops from rice to less water-demanding crops. Similarly, changes in the reliability of stream flow, and particularly a more intensive and potentially erratic monsoon rainfall (and pre-monsoon rainfall) are also reported to be affecting farming.

Effects on hydro-electric generation

Climate variability also affects hydro-electricity production, as many plants depend on predictable run off patterns, and are thus sensitive to climate variability (OECD, 2003).

Nepal's electricity generation relies mostly on the run-of-river type hydro power plants, and some river flows are insufficient to operate important plants during the dry season. This leads to planned rolling blackouts (often referred to as 'load shedding' in Nepal) and this has a high value of lost load. However, there are year to year variations, and outages can be exacerbated in low rainfall years, primarily in the dry season, but also because of the variability with the monsoon, because of its role in recharging reservoirs, such as the Kulekhani reservoir. In 2011/12, because of a comparatively wet monsoon and management regimes, the reservoir was filled, reducing (planned) load shedding (NEA, 2012).

Earlier studies (USAID-SARI, 2003) have highlighted the high economic costs from the poor quality of electricity delivery in Nepal. This study reported that approximately 8% of industrial sector demand was not met due to planned and unplanned interruptions, and that the industrial sector losses in Nepal attributable to unplanned interruptions averaged at 0.49 US$/kWh and 0.14 US$/kWh for planned outages. The outages were estimated to lead to an economic loss in Nepal's industrial sector amounting to US$24.7 million a year, which was equivalent to 4.4% of the industrial sector GDP or 0.5% of national GDP in 2001. Recent analysis has also highlighted that these issues continue (Shrestha, 2010) and have macro-economic impacts on the country.

It is also possible to provide some indicative analysis of the influence of climate variability on electricity generation and the subsequent impact by looking at the variability in generation and unserved demand between low and high rainfall years.

This study has considered planning forecasts from the NEA, as well as modelled analysis using the VALORAGUA model and the analysis of different hydrological conditions, based on analysis of historic data (presented in Chapter 7).

Using the information from recent electricity sector planning, the analysis has compared the forecast load shedding for 2011/12 with the actual levels (NEA, 2012). NEA projections indicated there would be a requirement for up to a maximum of 18 hours of (planned) load shedding per day per consumer during the driest months of January, February, March and April. However, due to factors mentioned earlier (i.e. the management regime and comparatively wet monsoon), itrestricted the 'load shedding' hours to 12 per day per consumer. This simple example highlights the potential effects of climate variability - in this case a 50% difference during dry season months between more dry and wet rainfall years.

As observed above, the level of planned outages avoided (6 hours a day per consumer), combined with the number of industrial and commercial consumers (NEA, 2012), their average electricity consumption, and the value of lost load for planned interruptions (US$0.3/kWh, updated to 2013 prices) indicates a possible difference between wet and dry years of as much as US$34 million, equivalent to around 0.2% of GDP. In practice, some of the unmet electricity demand will be offset by diesel back up, although the higher marginal costs of diesel generation would mean higher costs. Moreover, this value only includes industrial and commercial consumers

- the costs would be higher when domestic consumers are included (though the lack of a VOLL for domestic consumers means this has not been calculated).

A more sophisticated analysis of the impact of rainfall and river flow variability has been derived from the modelled analysis of energy generation from run-of-river plants under different hydrological conditions, using five hydro-conditions (very wet, wet, average, dry and very dry) based on analysis of historic data over 30 years (presented in Chapter 7). The annual energy generated (GWh) is estimated to be 175 and 190 GWh less in dry and very dry years respectively. Using an average VOLL, this is estimated at $53 million and $57 million respectively (current 2013 prices), equivalent to around 0.3% of current GDP. Based on the probability of occurrence of these hydrological conditions, the analysis estimates that on average, the costs of rainfall and flow variability on hydro-electricity generation is equivalent to 0.1% of GDP.

Hydro-electric plants are also subject to the risks of floods and droughts - including risks from Glacial Lake Outburst Floods (GLOFs). Indeed there was the loss of a multi-million dollar hydro-power facility (which had capital cost of approximately NPR 45 million) in 1985 due to a GLOF event (OECD, 2003) and more recent loss of micro-hydro plants from floods (Paudyal, 2011).

Major floods can also lead to large sedimentation deposits. Sediment can affect dams and reservoirs, and hydropower plants (both storage and run-of-river), shortening the economic life of such infrastructure. Finally, increased soil erosion from heavy rainfall and flooding leads to high sediment loads in rivers, which can affect the useful storage capacity of reservoirs and cause silting of irrigation canals and damage to hydro-electric turbines and water control structures. This can increase maintenance levels, increasing downtime and leading to lost hydro-electric production.

4.4. Gender Dimension

Nepal has developed policies plans, programmes and mechanisms for addressing climate change (Climate change Policy 2011, NAPAs, LAPAs,) where women's differentiated impacts, capacities and larger engagement are acknowledged but addressing it with built in mechanism with clear methodological procedure is still lacking. There is a general assumption that every member in the community will be benefited equally.

Contrary to the above assumption, many reports argue that climate change magnifies existing inequalities (Angula, 2008, Dhakelman 2008) reinforcing the disparity between women and men in their vulnerability to and capability to cope with climate change. Due to the fact that focus on gender differentiated impacts of the detail information have not been collected and documented, the information on the impact of climate change on women is scarce, not only for Nepal but internationally too. Climate change contributes to impacts on women because of the conjunction of the feminization of poverty and environmental degradation caused by current climate variability and climate change. The IPCC states that those who are already the most vulnerable and marginalized will experience the greatest impacts (IPCC 2007), as the major economic impacts will fall on low-latitude agriculture, the dominant source of livelihood for the world's poor. Nepal's Human Development is almost one third lower than it could be if it were more equally distributed (HDR, 2010) and by 2050 "the South Asia Human Development Index (HDI) would be 12% lower than the baseline in an "environmentally challenged scenario" and globally 15% lower in more adverse "environmental disaster scenario"[1] (HDR 2011).

To illustrate this, women of upper Mustang and Olangchung gola areas work nearly 17 hours a day on average compared to 10.5 hours a day for men, the time spend on fetching water is one reason. In addition, health and fuel-wood scarcity is making girls' and women's work more time-consuming, difficult, and prone to security risks (MoEnv, 2011).

4.5. Case Studies

The analysis and vulnerability maps (presented earlier in this chapter) reveal a high level of spatial variation in impacts across the country, reflecting differences in climatic and agro-ecological zones. There are also large differences in the distribution of impacts across groups in society (by gender or income level) for Nepal. To explore these issues, three local case studies using primary household surveys were undertaken to complement the national level focus. These also investigated community based perceptions of current climate variability and trends.

The first case study focused on an issue that was difficult to capture in the national scale analysis: the additional impacts of hailstorms. The second case study explored the distributional impacts of flooding and household responses. The third case study focused on agriculture in the mountainous agro-ecological regions.

Impact of hailstorms on crop production In Kaski District

In addition to the impacts of water-related disasters from current climate variability, there is also an impact of hailstorms, particularly on agriculture. These are not included in the standard assessments of variability and trends or climate natural hazard mapping (e.g. in the NAPA). To address this issue, the study undertook a case study to investigate the potential impacts and trends in hailstorms at the household level, with new primary survey work.

According to the Nepal Disaster Report (GoN, 2011), the most frequently occurring disaster during the months of March/April and October are hailstorms. In addition to summer crops, hailstorms can also damage winter crops, especially in the mountainous areas of the country. Although most of the hail is relatively small in size, there have been cases of larger hail stones, which has caused extensive damage to standing crops and even inflicted injuries and death. Major damage from such storms has been recorded in eastern Nepal (1980) and mid-western Nepal (1983).

Recording of hailstorms requires more advanced meteorological station equipment, and the existing DHM network does not record these events. There are, however, event records in the Disaster Inventory System (DesInventar). It records 585 hail events across Nepal between 1971 and 2007, shown in Figure 4.14. below. Nearly 40% of these (232 events) occurred in the Western Region. There is some indication of an increasing trend in the number of hailstorm events over the past three decades, though some caution is needed in interpreting these events over time, due to improvements in monitoring and reporting.

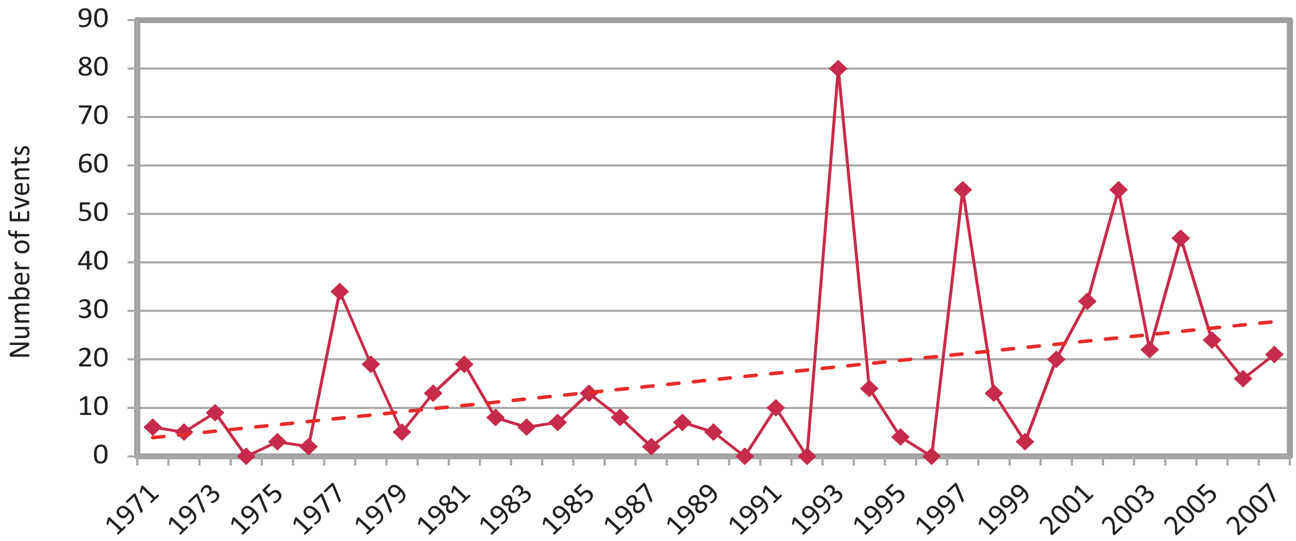


Figure 4.14. The total number of hail stone events in Nepal from 1971-2007

Source: DesInventar, 2013.

The case study investigated the impacts of these events on communities and livelihoods, focusing on groups that were dependent on agriculture and potentially vulnerable to hail storm damage. The case study focused on the Kaski District. This lies in the Western Region of Nepal and covers an area of 2,017 km^2 and has a population of 492,098 (CBS, 2011). This district experiences unusual rainfall patterns, with high rainfall and decreased winter monsoon rains. From 1971 to 2007, 55 hail events were recorded in this district. Most of the households in the district are smallholders, and the average plot of land is small (around 0.5 ha). Agriculture is the main occupation of approximately half the households surveyed, but 60% of households reported food shortages. This makes them highly vulnerable to climate variability and any impact that reduce agricultural yield or damage crops (food and cash crops).

To assess the perceptions of the community on the frequency and intensity of hailstorm events over time, and their related impacts, three VDCs (Village Development Committees) - Pumdibhumdi, covering 32 km^2; Sarangkot covering 18 km^2 and Lumle covering 53 km^2 - were selected within Kaski District, and 96 households were randomly selected to take part in a household survey. These were complemented with Focus Group Discussions (FGD) and Key Informant Interviews (KII) to assess hailstorms and resulting crop damage/loss in these communities.

The study found that most people surveyed within the communities (around 80%) believe that hailstorms have been occurring more frequently in recent years. Based on community recollection, around 20 major hailstorm events have occurred in the vicinity of their communities over the last 35 years (up to 2012), and these were reported to have caused significant damage to crop production, livestock and infrastructure (including water tanks, pipelines, and window panes). Communities also mentioned that deaths and injuries to people have occurred, although these are relatively rare. The case study found a strong community perception that these events have been increasing in frequency and intensity. Respondents estimated losses ranged anywhere from an average value of 10,000 NPR to up to 62,000 NPR per household during any particular hailstorm event.

The high damage in some years is also shown in the DesInventar database, which records the percentage of crops destroyed or damaged, the area of land affected by a particular hailstorm event, and number of livestock affected or killed. Of the 55 events in the Kaski District, the database reports high damages to wheat, maize and rice crops in various years, as well as to vegetables, oranges and winter crops. The worst events are reported to have damaged 75% to 100% of key crops (e.g. in some areas in 1977, 1980, 1985, 1986, 1987, 1988, 1995, 1997, 1998, 1999, 2002, 2004). The damage in 1997 was reported at some US$2 million, due to the extensive damage to rice and millet (around 50%) and a similar amount in 1998. The damages in 1999 are reported at US$5 million due to the damage to vegetables, crops and rice. The database also records 13 deaths from hailstorms, the most recent of which was in 2005.

The data clearly shows major impacts on agricultural production and incidents of human fatalities and injuries. This highlights an additional impact of current climate variability. While data on the economic costs is partial, major damages to crop harvests are high in some years, ranging from 50%-100% of the crop being damaged in affected districts, resulting in large economic costs in some years. Around 85% of households use plastic tunnelsor adopt greenhouse farming to address the problems of hailstorm damage (an autonomous adaptation response); however, 15% households did not adopt any preventive measures. They had also appeared to change cropping patterns, partly to cope with the hailstorm events, but also because production was shifted to major cash crops, particularly coffee and vegetables, which is driven by the need for further source of income.

Regarding the action taken by the Government of Nepal to mitigate vulnerability due to hailstorm events, the majority of respondents expressed the view that effective initiatives had not been taken. Some reported that some compensation had been given in terms of money, training, awareness programs, tunnel technology and several conservation efforts had been carried out by the government.

It is highlighted that the future impact of climate change on hailstorms is unclear. Botzen et al. (2010) studied the potential effects of climate change on extreme weather, notably hailstorm, and reported that damaging hailstorms result from severe convective weather, associated with the occurrence of intense precipitation events (linked to temperature). While the future pattern of extreme events and heavy precipitation is uncertain, heavy precipitation events and the increased intensity will likely increase during the monsoon; thus there is a potential for these trends to increase.

Impacts of Rapti River Flooding in Banke District

The second case study investigated the impact of river floods in the West Rapti River basin. This basin is one of the most flood prone river basins in Nepal and extreme floods have occurred in 1977, 1981, 1983, 1999, 2000, 2003, 2005, 2006, 2009 and 2012. Almost every year during the monsoon season, villages in the Lower West Rapti Basin in the Banke district get inundated from flood waters. This is especially true for those areas along the Nepal-India border.

The Banke District has been ranked as the 7^{th} most vulnerable district in terms of population at risk of food scarcity, landslides and flood disasters in the NAPA (GoN, 2010). It covers an area of 2,337 km^2. Banke has a high population of 491 thousand people (CBS, 2011). It also has low infrastructure facilities, and villages suffer from drainage congestion and inundation problems due to unplanned growth, poor design of the drainage system, and insufficient waste disposal practices (ICHAMR, 2008). Gautam and Phaiju (2013) report that the most affected villages in the Lower West Rapti Basin are Betahani, Holiya, Binauna and Phatepur. The case study set out to investigate the impacts of floods on livelihoods in two of these villages (Holiya and Betahani). It also considered the distributional impacts of flood (especially from a gender perspective) as well as information on current community adaptation strategies (autonomous adaptation). The latter allows analysis of whether these existing responses are sufficient to address the changing patterns with climate change. 96 Households were randomly selected to take part in a household survey (a questionnaire) and these were complemented with Focus Group Discussions and Key Informant Interviews.

The survey found that agriculture was the main livelihood source for households. Although just over a quarter of respondents produced insufficient domestic food production: nearly all of them reported a loss of agricultural products due to flooding. When the estimated losses were combined with production statistics, this leads to an estimated loss of 2.7 Mt per hectare in Banke. In major flood years, such as 2012, agricultural losses were very high (60%). The survey also found that around 85% of households suffered from increased water borne diseases after the 2006 flood. This implies that health impacts could actually be an important impact of these events, which is omitted from most assessments (as are the economic costs of health impacts from welfare losses). The community also reported changes in the intensity as well as increased frequencies of extreme flooding events.

A key finding of the household surveys was that many of the respondents (around 32%) had actually migrated from their previous homes due to landslide (though these were mostly relocations between villages in the same district), or from other highly affected flood areas. The areas they migrated to were also at high risk of flood. Around 80% of respondents reported at least some annual flood hazard, and over the last forty years, there have been at least 12 major flood events. The losses were primarily due to crop losses (48%) followed by damage to land (38%) and property. There were distributional impacts, with the survey reports finding the highest impacts on children and poor females. For women, many of these impacts arose post event, e.g. associated with health impacts (themselves, and through having to care for children). Community recollection of major events aligned with historical extreme event records and the majority of households (73%) believe that the frequency of flooding events has intensified over the last decade.

The survey and focus group discussions also provided useful information on household level responses to flooding. Those who could afford it have reinforced their homes by building in cement/concrete (not mud), installed a cement barrier around their house, or raised the plinth of the house (though only 4% of those surveyed had done this). Some (5%) have intentions to migrate to another part of the same community or to a neighbouring community. Finally, some (10%) have changed their cropping systems (or patterns, moving to mixed crop systems or planting different and more resilient crops), and storing grain in metal drums. All of these are forms of household level adaptation (primarily autonomous adaptation, responding reactively to current extremes). At the community level, with support from the Government and development partners, an Emergency Response plan has been developed. There is also an early warning system, and life jackets/boats have been distributed. There have been disaster preparedness trainings as well as post-disaster response relief (e.g. food distribution). Some embankment building construction has taken place, and some bamboo barrage defenses, but neither of these was considered sufficient.

Envisaging future challenges, there is some existing analysis of future climate change on flood and associated risks in this region. The study in the Lower West Rapti Basin (NDRI and UNESCO-ICHARM, 2012) is summarised in chapter 7. This study projects a very large increase in future flood damages for this area, with a potential increase of more than 50% and even as high as 200%. It is likely that this level of flood intensification and flood frequency projected will significantly exceed the current local coping capacity and the small-scale measures which are currently in place. While the Early Warning System (EWS) would reduce the loss of life, it would not address other losses and damage. This highlights the need for enhanced adaptation. In relation to future climate change, respondents and group discussions identified the need for structural protection measures along the river, as well as shifting from the vulnerable areas.

Buckwheat Farming in Mustang

The third case study assessed the impact of climate variability in the mountainous agro-ecological region of Nepal, looking at Buckwheat, a principle crop grown at higher elevations (Baniya et al., 2000). The study focused on the Mustang district, one of the most rural and geographically constrained areas, which experiences low rainfall (semi-arid). The district is ranked as highly vulnerable (the third highest ranking in the country) in the NAPA (GoN, 2010).

Production of Buckwheat, which comprises almost 30% of the total crop production in the district, is the main staple dish, has been affected in recent years, potentially due to the higher level of warming that has occurred at higher elevations in Nepal (see earlier in this chapter). Climate change is likely to exacerbate these impacts.

The study was conducted in four village communities: Lete, Marpha, Jomsom and Kagbeni. Using participatory tools, 96 randomly selected households were interviewed and the information was complemented with Focus Group Discussions and Key Informant Interviews.

The interviews revealed a high proportion of female headed households. Income levels were low (around 30% of households are poor) and women contribute 25% of income (on average). The majority of households (88%) depended on agriculture (own land and shared cropping) supplemented with remittances and some other activities. Average land size was very low (0.3 hectares per household). Buckwheat was an important crop, with almost all households cultivating the crop. The survey also found a high proportion of food insecurity in the area.

The results of the household survey reported decrease in Buckwheat production over the last decade, with climate being considered an important factor in this decline amongst many households. The survey found that the time taken to grow buckwheat had increased and productivity had declined, and some reported that there were increased pests, though other factors were also highlighted (e.g. the lack of labour). This is consistent with studies that indicate shade conditions and temperature affect the viability of pollen and seed and that bud formation is reduced as temperature increases (Wang and Campbell, 2004). The survey also found flooding and landslides were important in local impacts, and community perception was that such events have increased, with increasing precipitation (including increased intensity). These changes match meteorological observations of increasing intensity and duration of rainfall.

4.6. Overall findings

The overall analysis shows that direct economic costs of current climate variability in Nepal are very high. These impacts have major impacts on livelihoods affecting hundreds of thousands of people in major extreme years. They also show that Nepal experiences very high economic costs from current climate variability. This includes the costs of water-induced disasters as well as the impacts on Nepalese agriculture and hydro-electricity generation. There is a strong seasonal dimension to these impacts, with high costs from excess rainfall during the monsoon season (from floods) and from low rainfall during the dry season (due to low flows and hydro-electricity outages). There is also a strong distributional difference in the patterns of exposure across the country, for example, the highest risks of river flooding are in the Terai, whereas the highest risks of landslides and GLOFs are in the Hills and Mountains.

When combined, the annual costs of current climate variability in these three sectors are estimated to be 1.5% to 2% of GDP equivalent on average (approximately US$270 million in 2013 prices). However, there is high variability between years, and the annual costs have been found to be as high as 5% in extreme years, e.g. during major flood or drought years. These are dominated by water-induced disasters, though major drought years are also important. When indirect and macro-economic costs are added, the total costs are likely to be 25% to 100% higher.

The size of the adaptation deficit in Nepal is high by international standards. The recent IPCC SREX study (IPCC, 2012) reviewed losses from natural disasters. During the period from 2001 to 2006, losses amounted to about 1% for GDP for middle-income countries, about 0.3% of GDP for low-income countries and less than 0.1% of GDP for high-income countries (IPCC, 2012). However, in small exposed countries, particularly small island developing states, losses expressed as a percentage of GDP are high, exceeding 1% in many cases and 8% in the most extreme cases, averaged over both disaster and non-disaster years for the period from 1970 to 2010. The losses in Nepal are similar in scale to these countries, and thus it can be seen that the impact of current climate variability and extremes is significant.

A key conclusion from this analysis is that Nepal is not adequately adapted to the current climate and therefore has an existing adaptation deficit, which requires urgent and immediate action. Adaptation to future climate conditions is less likely to be effective when current adaptation deficits are not also addressed (Burton, 2004). Addressing these existing impacts will lead to immediate economic benefits, and are therefore no-or low-regret in nature.

5 Climate Model Data and Projections for Nepal

Key Summary Points:

- To assess the future impacts of climate change (in work-streams 2 and 3), climate model projections are needed. However, the modelling of climate change in Nepal is extremely challenging, due to the large differences in elevation and the complex nature of the regional climate. All future projections have a high degree of uncertainty and the analysis of impacts and adaptation need to take this into account.
- As part of the study, existing climate model projections for Nepal were used as an input for the impact models. The study focused on downscaled regional climate model runs, because global climate models do not provide the necessary level of detail. However, only a small number of these regional climate model runs exist for Nepal. Ideally all of these would have been used to provide an inter-model comparison, but due to differences in time period, data resolution and bias correction, only the Indian Institute of Tropical Meteorology model runs were found to be suitable. This study provides data for the A1B scenario - a medium-high emission scenario that does not consider global mitigation.
- The regional climate model run for this A1B scenario projects a strong increase in temperature across the country, with average maximum and minimum temperatures increasing by 3° to 5°C by the end of the century (across seasons and areas) relative to the baseline period. The changes in precipitation are more varied, with high spatial and temporal differences. Depending on the future time period and the region, there are increases or decreases projected, though there are indications of increasing extreme precipitation.
- As this data set is only for one regional climate model for one socio-economic scenario, a comparison was made with other projections, including statistically downscaled projections (which downscale global model results with local meteorological observations) to consider uncertainty. The analysis found a consistent warming trend across all of the projections, but with variations by scenario and model. However, the analysis found very large differences in projected rainfall, even in the sign of change, with large variations across seasons and locations. This uncertainty was also present for extremes such as heavy precipitations. To explore this additional data for the ECHAM5 parent GCM was also used for selected basins for water sector impacts.
- These uncertainties are compounded by the effects of temperature (and precipitation/snowfall) on the levels of glacial ice reserves and melt-water. A number of studies report that this may increase short to medium term water availability due to higher melting with rising temperatures, but then lead to a decrease in the longer-term, at least for some river basins, though there is considerable uncertainty.
- The review findings reinforce the need to work with multi-model inter-comparison data in Nepal, and cautions against the use of central projections for optimised responses. A direct implication is the need to recognise this uncertainty in planning adaptation response, and in the design of iterative strategies, noting that this uncertainty is not a reason for inaction.

- Alongside the future projections of climate, the study also considered strong socio-economic changes in Nepal. These are likely to be as important as future climate change signals in the sectors considered, and there is a need to link them together when considering climate change and adaptation responses. These include future changes in population and per capita income. These signals can act positively as well as negatively in terms of future risks.

5.1. Introduction

The analysis of the future impacts and economic costs of climate change requires projections of climate change. These are produced by climate models. These models use future scenarios (of future emission pathways) to make projections of changes in temperature, precipitation and other meteorological (and hydro-meteorological) variables over time.

The projections are made using global climate models that operate at a high level of aggregation. However, these can be downscaled to regional levels either with statistical downscaling or with regional climate models. The study first reviewed information from a large number of climate model projections, to build up a picture of future change in Nepal, and to select climate model projections for the analysis of future impacts.

5.2. Global Climate Model Projections for Nepal

The study reviewed the available climate model projections for Nepal. The study started with a review of global climate model projections for Nepal. A number of studies, notably McSweeney et al. (2011), have reviewed the results of a number of future scenarios and climate models.

These studies show a consistent warming trend for Nepal in all scenarios and for all models. However, as shown in Figure 5.1. below, the increase in annual temperature varies strongly across different socio-economic scenarios (captured by the different IPCC Special Report on Emissions, scenarios A2, A1B and B1), and across different models. These show a range than spans from 2 to 5°C of annual mean temperature increase by the end of the century.

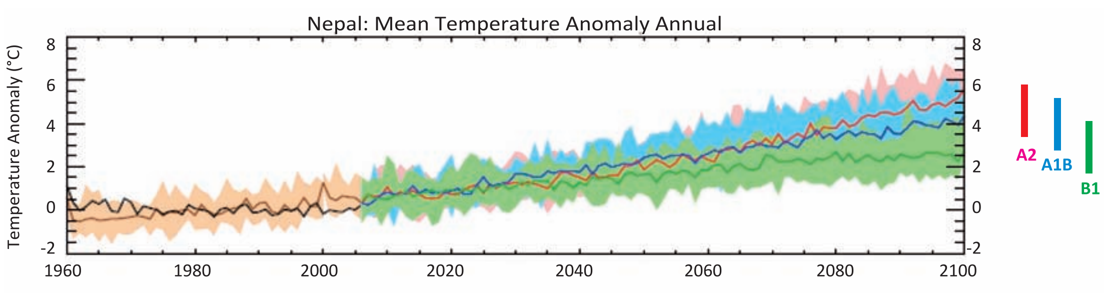


Figure 5.1. Trends in annual mean temperature for Nepal for the recent past and projected future simulated by 15 models for each emission scenario

Source: McSweeney et al. 2011.

The projection of future rainfall in Nepal is much more challenging, as shown by the equivalent projections from McSweeney et al. (2011) in Figure 5.2. Some models project an increase in annual precipitation all over the country, although the increase in rainfall is primarily associated with the monsoon season, whereas other models project a decrease. These changes also need to be considered against the background of high inter-annual variability (see observed data in the figure to the left), and the change in annual precipitation is difficult to detect in the context of this high natural variability. Overall, McSweeney et al. (2011) report a wide variation across scenarios and model projections, with changes between -30% and +100% in the annual rainfall anomaly.

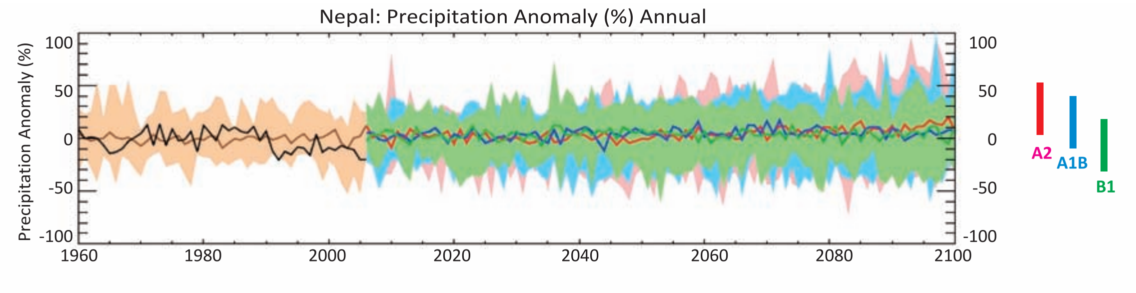


Figure 5.2. Trends in annual rainfall for Nepal for the recent past and projected future simulated by 15 models for each emissions scenario. % anomaly

Source: McSweeney et al.

The uncertainty associated with these future projections is important. There is a range of future emission profiles, ranging from low to high emission futures, and many climate models. Together, these can lead to very different results, even for variables such as average temperature. For precipitation, the differences across scenarios and models can even alter the sign of the change (+/-).

It is clear that over reliance on a single scenario, and especially a single climate model, is likely to give misleading results, and a critical finding for the study - and for future work - is the need to consider the range of uncertainty.

5.3. Downscaled Climate Model Projections for Nepal

Global climate models, as considered above, work at a typical grid resolution of between 150 km and 300 km (Meehl et al., 2007). This level of resolution cannot capture the huge differences in elevation across Nepal, as elevation increases by over 8000 metres from the Terai to the highest mountains, over a distance of less than 250 km. There is also a large variation in local topography, that result in significant local climatic differences e.g. between adjacent catchments (Alford, 1992).

For the analysis of impacts, it is therefore necessary to consider downscaled climate data. The study has considered two alternative approaches for producing downscaled data. The first uses empirical (statistical) downscaling aligned to the local meteorological station data. The second uses Regional Climate Models (RCM) which typically work at grid level of between about 25 km and 50 km.

Statistical downscaled results

An analysis of statistically downscaled data, derived using local meteorological data stations with global climate model data was considered, using the University of Cape Town archive (A2 scenario for the 2040-2060 time period, UCT, 2012). This considers 9 global models, downscaled to individual meteorological stations for Nepal. An example of the downscaled output is shown for Kathmandu is shown in the box below (for 2040-2060 period for the A2 scenario-a high emission scenario, Nakićenović et al., 2000). These show broadly consistent trends for temperature, but very complex and uncertain projections for precipitation, even for a single station site. Analysis of different station sites in Nepal show similar relative increases in temperature, though with a slight difference in warming across the year. While the relative increase is similar in all areas of the country, this arises on top of very different baseline temperature profiles, due to the wide range of elevation. For precipitation there are much larger differences, with a wide range of changes in rainfall from different driving global climate models, for regions of the country and months of the year.

Regional Climate Models

There are several families of Regional Climate Models that have been applied in Nepal (NCVST, 2009; Karmacharya et al., 2007; GCISC et al., 2009). The DHM study (Karmacharya et al., 2007) projects warming in all seasons in the mid-21st century (2039-2069) with the warming in the northern part over the high Himalayas greater than that in the southern part. It projects the highest increase in temperature in the winter and lowest in the pre-monsoon season in both the east and west of Nepal. The annual mean temperature was projected to rise in the range of 1.7°C in the southern region of the country to 2.5°C in the northern region. It also projected a decrease in annual precipitation in large parts of the country, mainly in eastern and southern Nepal (by up to -30%) but no change in precipitation over north-central and north-west Nepal, and with varied seasonal changes. Further regional climate models are discussed in the later section, in relation to the choice of data for the impact modelling.

Statistically downscaled data

Temperature. All the climate projections show increasing temperature (average and extremes), though the level of increase varies slightly across the 9 global models. Figure 5.3 below shows the monthly daily maximum temperature for the 2040-2060 time period (A2 scenario). The top box shows the absolute modelled temperature, with the current climate shown in grey, and the future climate with climate change shown in pink. The bottom box shows the increase from the current (modelled) climate in blue. In both cases, the width of the lines represents the range across the different models.

Rainfall. The projection of future rainfall is more complex. The projection shows changes in monthly rainfall for Kathmandu, showing how the changes vary across the models for the 2040-2060 time period (A2). The top box shows the absolute modelled precipitation, with the current climate shown in grey, and the future climate with climate change shown in red. The bottom box shows the change from the current (modelled) climate in blue. In the bottom graph, the height of the columns represents the span of the different models (with the average line also plotted).

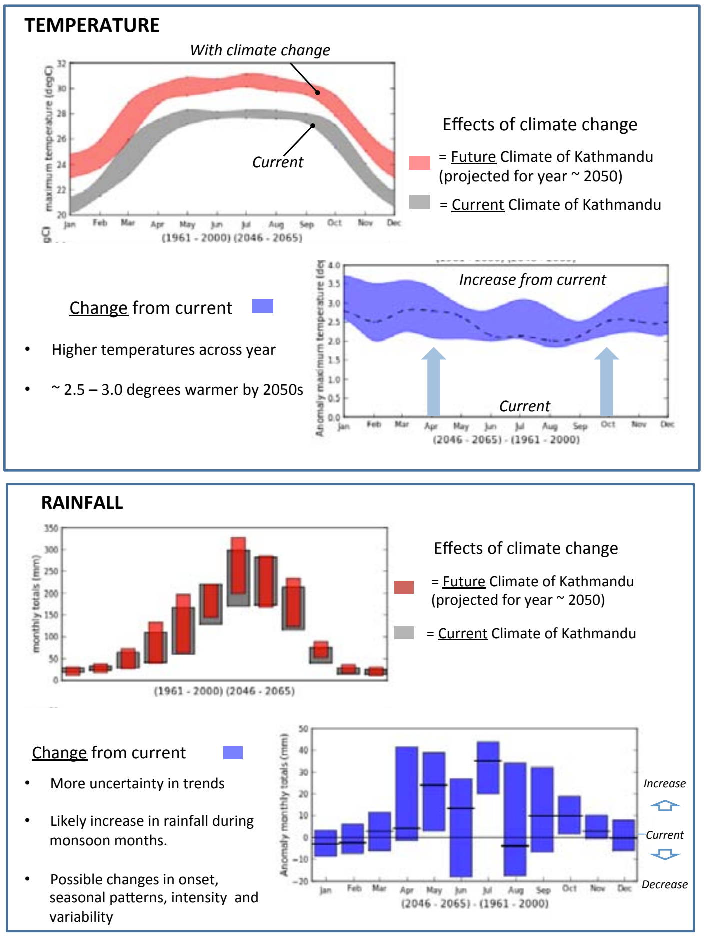


Figure 5.3. Statistically Downscaled Temperature and Precipitation Projections for Kathmandu (A2, 2050)

Source: Climate Systems Analysis Group (CSAG), University of Cape Town, UCT (2012).

While the application of regional climate models to Nepal is very promising, and starts to address the complexities of the local climate, it is stressed that the use of a small number of regional models does not capture the range of climate model uncertainty (which is very large), i.e. it is not a substitute for multi-model ensemble analysis. Indeed, it can even be counter-productive by giving apparent confidence without capturing the underlying model bias, e.g. whether the model is warmer, wetter, drier, etc. These issues are particularly important in relation to changes in complex regional weather (notably monsoon processes), the representation of which varies significantly between models, and in relation to the projection of extreme events.

The analysis above clearly highlights that for rainfall, variability and extreme events (e.g. floods and droughts), there are large differences between models, and there is a need to consider the outputs of a range of models, rather than a single central projection. For this reason, the use of regional climate model data in this study has been complemented by an analysis of uncertainty from climate models, presented later in this chapter.

Looking towards future assessments, even if additional RCM runs emerge, this will not solve the issue of capturing the high level of uncertainty for Nepal. Instead it is essential to recognise this uncertainty. Rather than ignoring uncertainty through the use of central projections and optimised responses, or using this as a reason for inaction, it is necessary to plan robust strategies to prepare for uncertain futures.

5.4. Climate Model Availability and Selection Criteria

Running climate models to produce new climate simulations is a very time and resource intensive process. This was not possible for the current study, and a number of existing data sets from regional climate models were therefore considered for the study.

There were three main sources of climate projection data available, produced by different models, with different time series, at different spatial scales, and for different climate scenarios. These included:

1. The analysis undertaken as part of the analysis for the 2nd National Communication, which has PRECIS output for A1B for a full time transect from 1961-2098;
2. The Department of Hydrology and Meteorology (DHM) climate portal, which has three RCM outputs for the A1B scenario for the 2030-2060 period (the PRECIS model, the Weather Research and Forecasting (WRF) model and RegCM4; and finally,
3. The RCM output (PRECIS) from the Asian Development Bank's (ADB) climate projections used in the second study on Regional Economics of Climate Change in South Asia (RECCSA II).

In looking at these various outputs, a number of issues are highlighted:

- The first data set, produced by the Indian Institute of Tropical Meteorology (IITM), provides data for one climate scenario (A1B), and one model (PRECIS), but it has downscaled data for a continuous time-slice that are carried out for a continuous period from 1961-2098 and has daily bias corrected data available.
- The DHM climate portal has the advantage of a multi-model sampling, with three bias corrected RCM outputs for the A1B scenario for one time period (2030-2060). The models are: the PRECIS model; the Weather Research and Forecasting (WRF) model, which dynamically downscales General Circulation Model (GCM) simulations; and the RegCM4, which is the fourth version of the Regional Climate Model system RegCM. While the use of multi-model data is preferable, the bias corrected data was only available on a monthly basis, but not on a daily basis.
- The ADB RECSSA climate model outputs were potentially interesting, especially as they sample across three future socio-economic scenarios (A1B, A2, B2) for one regional climate model (PRECIS) at a high grid resolution (30 km). However, the time series data produced is not a continuous data time set, with only decadal (10 year) outputs for future time periods. It is not recommended to use such short time-slices for climate model data, because of the high variability. The convention in impact assessment studies is therefore to use 30 year time periods. This is due to the natural variations that occur in the climate (i.e. variability), and thus 30 years is generally necessary to assess climatic parameters with confidence, Given the very high variability in Nepal, decadal time periods were not considered sufficiently robust.

While there is no right or wrong choice on which model or projection to use, to meet the objectives of this study, and to align with the input requirements for the impact models, it was necessary to use continuous, bias corrected, time series data, for daily (rather than monthly) temperature and precipitation. The use of daily data is a requirement for both the agricultural impact modelling (using DSSAT) and for the hydrological modelling.

The only data set that met these criteria was IITM's climate projection data, derived from the PRECIS regional climate model, which included daily maximum and minimum temperature, and daily precipitation, at a spatial resolution of 50 km for the whole period (1961-2099) for 240 locations in Nepal. Even though this data set was selected for the study, the information from DHM's Climate Portal was also used in comparing model uncertainty (see below), as part of the qualitative analysis. It is highlighted that the DHM data had bias corrected monthly data, but not bias corrected daily data.

Ideally all of these data sets would have been used to provide a inter-model comparison, but due to differences in the time period, the level of data resolution (daily) and bias correction needed, this was not possible.

This highlights a priority for any future regional climate model runs for Nepal. There is a need to consider harmonisation procedures and the use of the model outputs in subsequent impact studies. This requires continuous time slices and daily data (with bias correction). It is also stressed that there is a need for multi-scenario and multi-model analysis so as to capture the range of climate futures.

Finally, the IPCC SRES A1B scenario (Special Report on Emission Scenarios, Nakićenović et al., 2000) is a medium-high emission scenario, and is similar to recent emissions, although it does not include future global mitigation. The full set of SRES scenarios included a higher emission future (e.g. A2), which would lead to higher levels of warming than A1B, but also lower emission scenarios (B2). It is highlighted that the most recent projections (e.g. IPCC, 2013) now use the new Representative Concentration Pathways (RCPs). These capture a broader range of scenarios, including global mitigation scenarios, and they will be important to capture in future analysis of climate change in Nepal.

5.5. Climate Model Results

The Indian Institute of Tropical Meteorology (IITM) provides data for the A1B SRES scenarios for one model (PRECIS), for 3 time slices: 2011-2040 (i.e. the 2020s); 2041-2070 (the 2050s); and the 2071-2098 (the 2080s).

The PRECIS A1B SRES simulation shows an increasing temperature trend for each time period across the country. By the end of the century (2098), the maximum temperature is projected to increase by 4.5°C in spring and 3.3°C in summer. The increases in minimum temperature are higher in winter (at 5.4°C) than in summer (at 3.4°C).

The changes in precipitation are more complex, with high spatial and temporal differences. The changes in rainfall vary with increases and decreases in different future time periods over different areas of the country. There are, however, some indications of increasing extreme precipitation.

5.6. Climate Model Uncertainty

As highlighted above, there is a very wide range of results from different emission scenarios and climate models. As the study has used one downscaled regional climate model for the quantified impact analysis, it is important to examine the potential uncertainty associated with a wider multi-scenario, multi-model ensemble. To do this, the study reviewed climate model uncertainty, and then transferred these uncertainty results to the interpretation of the impacts analysis in work-stream 3.

Analysis of uncertainty from statistical downscaled results

Figure 5.3 above presented the statistically downscaled results for Kathmandu. Figure 5.4 below shows the monthly daily maximum temperature for the mid-century projections (A2) for eight station sites across Nepal - for both current (grey) and future (red) and for the change relative to current (blue in the bottom figures). While the relative changes in temperature - and the profile of change across the year - are similar across all regions (shown in the blue figure), these arise on top of very different baseline climates. The additional effects of higher temperatures will, therefore, have very different impacts in the Terai as compared to the Hills and Mountains.

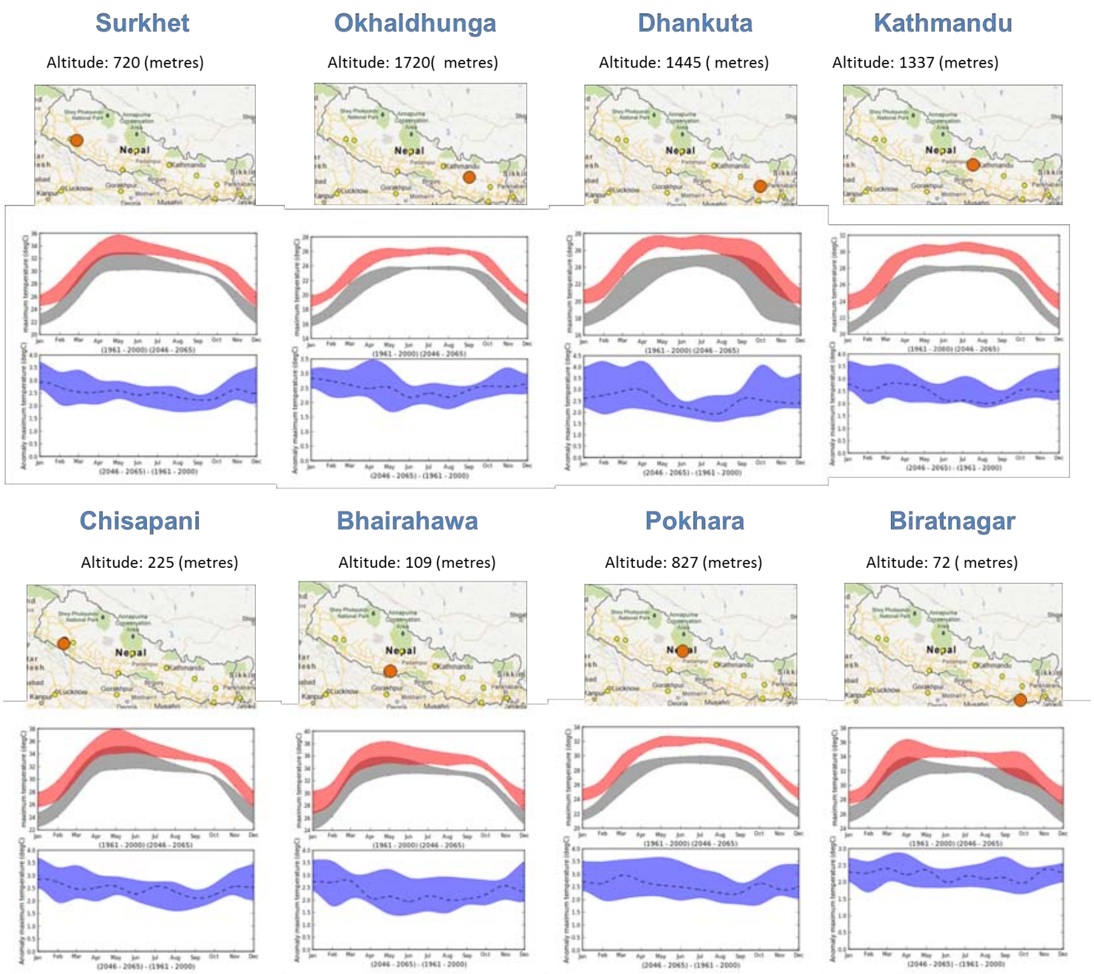


Figure 5.4. Monthly daily maximum temperature for the mid-century projections (A2) for different sites

Source: Climate Systems Analysis Group (CSAG), University of Cape Town, UCT, 2012.

Similar analysis of rainfall for the same eight station sites across Nepal are shown below – for both current (grey) and future (red) and for the change relative to current (blue in the bottom figures). These show much greater differences, with strong differences in the patterns of monthly rainfall across the year, and different precipitation trends in different parts of the country. They also show a wide range of projected future change in rainfall (reflected in the blue column height) that varies across the months of the year. In many cases, these include potential increases as well as decreases. While most models indicate an increase in precipitation during the monsoon months, there is by no means agreement across all the models on this change.

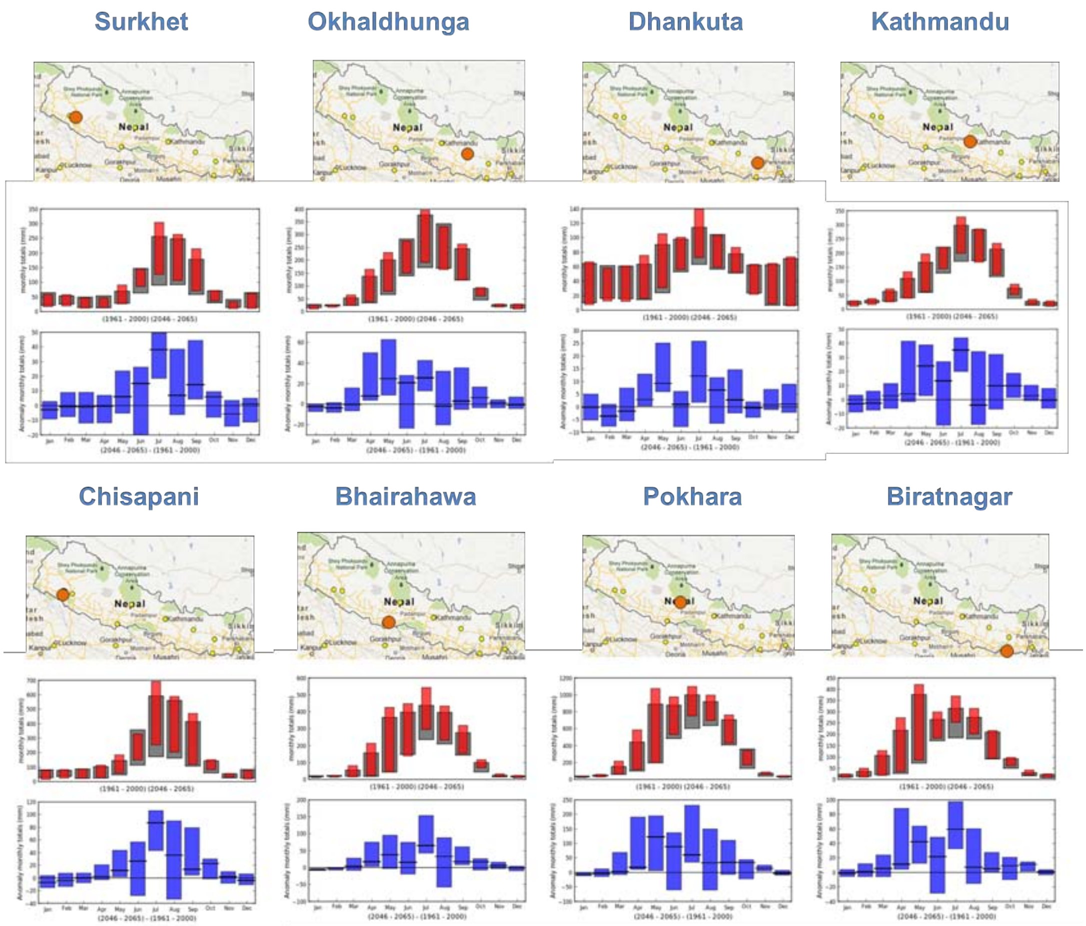


Figure 5.5. Monthly rainfall for the mid-century projections (A2) for different sites in the country

Source: Climate Systems Analysis Group (CSAG), University of Cape Town, UCT, 2012.

The projection of extreme events is much more challenging, but these are important in driving many of the impacts of interest to the study. In general, projections of future climate change suggest that there might be an increase in the intensity of high rainfall events (Meehl et al., 2000). A major scientific theory underpinning this is that a warmer atmosphere will be able to hold more water, thus likely to result in more intensive and frequent rainfall events. An analysis of the projected downscaled data for changes of rainfall extremes - looking at the change in monthly rain days in excess of 10 mm a day - mostly shows this trend. There are increasing numbers of days with high precipitation during the monsoon season, though the level of increase varies considerably across models. While some models project significant increases in precipitation (represented by the top of the columns), some show little relative change from current or even a slight decrease (represented by columns at or below the baseline).

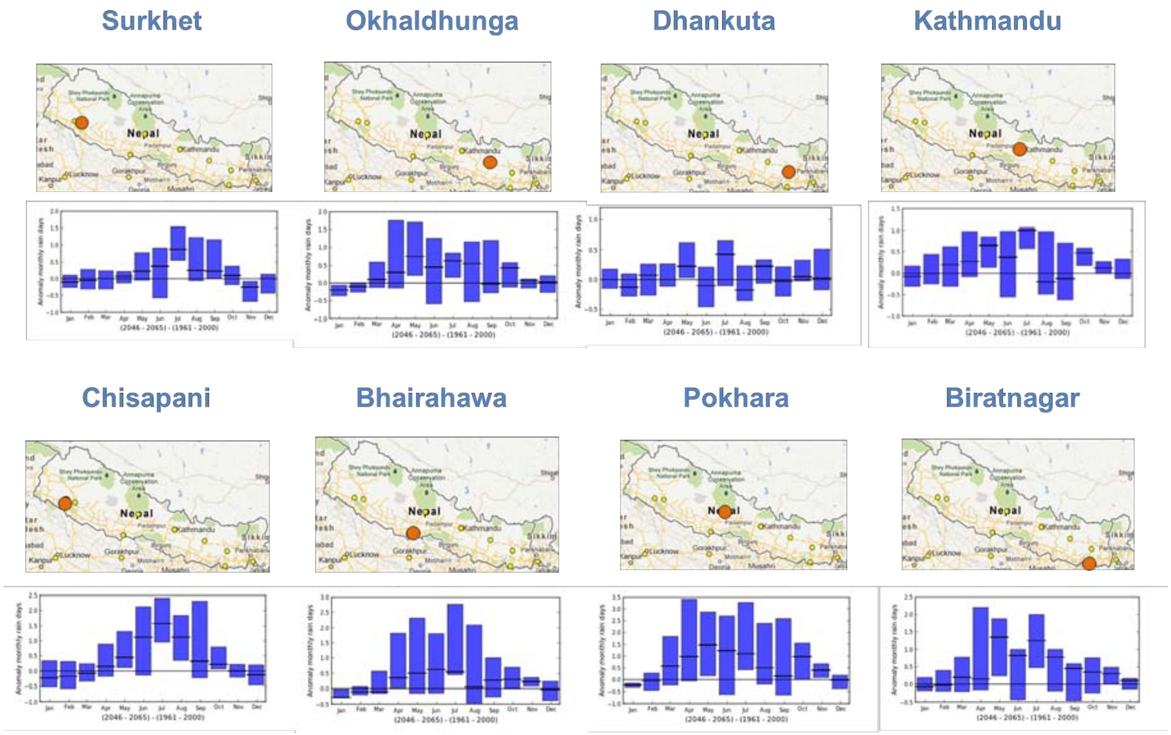


Figure 5.6. Monthly rain days (>10 mm/day), mid-century projections (A2) for different sites

Finally, in terms of the change in monthly dry spells (length in days), there is again a broad trend with an increasing dry spell duration during the dry season, but again, there is high variation regarding the change across the models (the span shown in the column height).

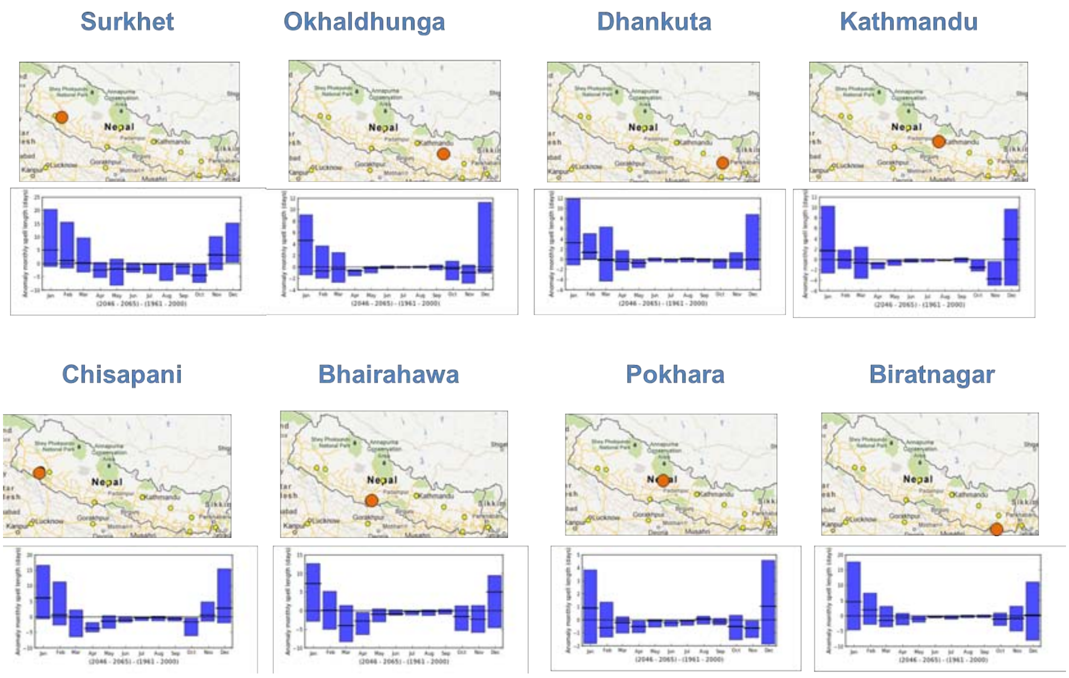


Figure 5.7. Monthly dry spell duration, mid-century projections (A2) for different sites in the country

Source: Climate Systems Analysis Group (CSAG), University of Cape Town, UCT, 2012.

Regional Climate Models

There are similar findings from a comparison of regional climate model runs. This can be shown with the results from the DHM climate portal, which allows comparison of several models, with three bias corrected RCM outputs for the A1B scenario. An example is shown below for total rainfall - which is the total rainfall (rather than the change). While the broad pattern of total rainfall is similar, there are important differences in the total rainfall projected, and large variations projected in specific areas, between different models.

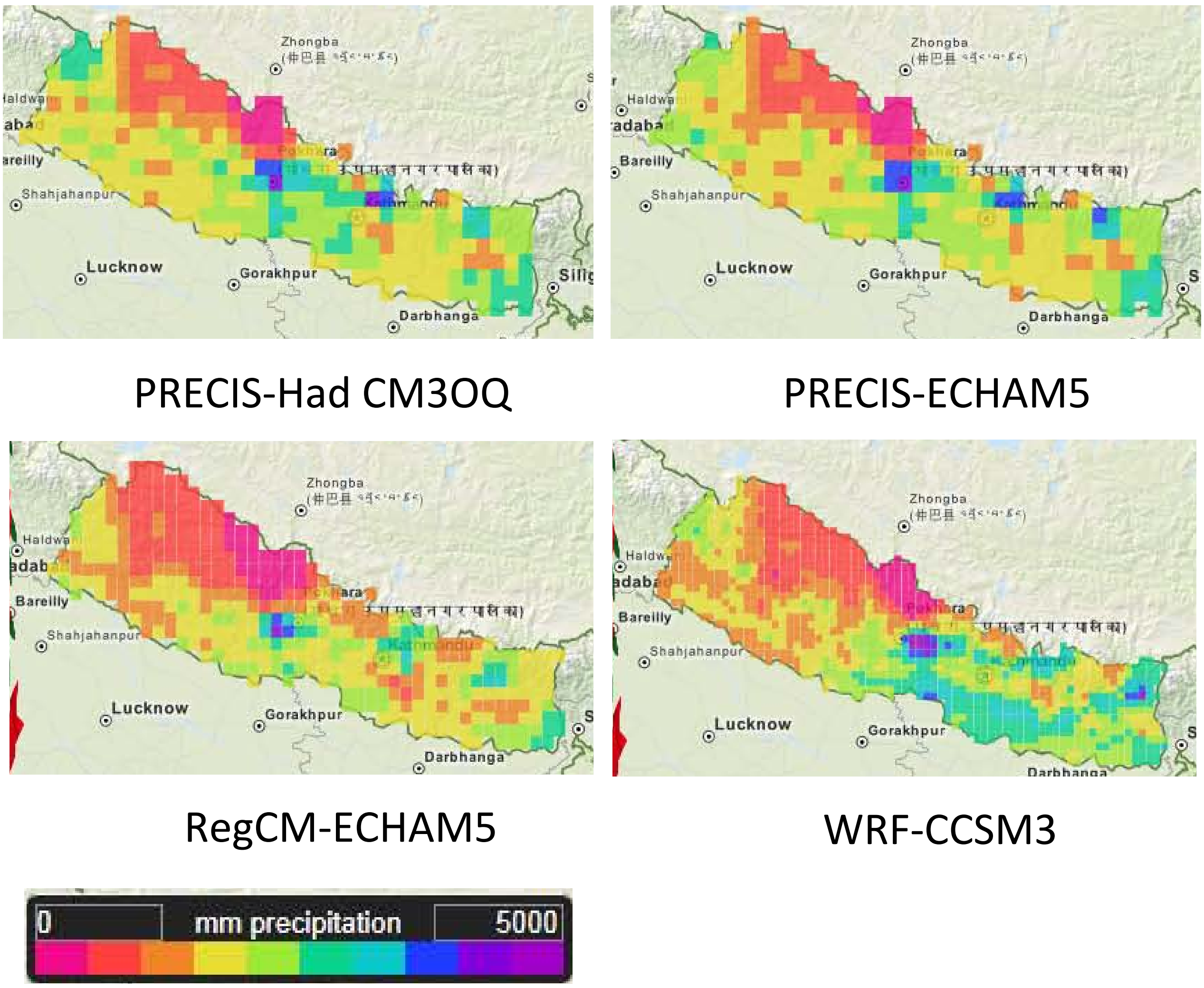


Figure 5.8. Total Annual Rainfall (2031-2060) A1B Scenario from Three Regional Climate Models (Bias Corrected) – combination of different GCM-RCM combinations

Source: DHM Climate Portal.

As highlighted in chapter 3, in order to capture climate model uncertainty regarding precipitation and river flow, DHM Data for PRECIS using the ECHAM5 parent GCM was also used for selected basins to complement the main IITM analysis.

Monsoon and Glaciers

As highlighted above, there are significant differences in the annual changes in temperature and precipitation. In relation to complex seasonal changes, these are even more uncertain, notably in relation to the likely changes in the monsoon. At a global level, the IPCC (2013) reports that while monsoon winds are likely to weaken, monsoon precipitation is likely to intensify due to the increase in atmospheric moisture. It also reports that monsoon onset dates are likely to become earlier or may not change much, and that the end of the monsoons will likely be delayed, resulting in lengthening of the wet season in many regions.

At the regional level, wider differences on potential changes are reported in the literature. Some studies project a weakened monsoon season, with less summer precipitation and a delay in the onset (e.g. Ashfaq et al., 2009), while others indicate an increase in the monsoon rainfall on a seasonal mean (e.g. Turner et al., 2012), highlighting the high level of uncertainty across the climate simulations and different patterns of change.

There is also a potential risk of a very significant (abrupt) change in the monsoon, which has been identified as one of a number of the global tipping elements (Lenton et al., 2008). These tipping points/elements are large-scale (non-linear) discontinuities that could push the climate system into undesirable states, and could lead to major catastrophic events, or pass thresholds that would trigger changes that would be difficult to control. Lenton et al. identify the destabilisation of the Indian monsoon circulation, with a possible switch to a weaker monsoon. While the information on the likelihood of such large-scale events remains highly uncertain, especially with regard to the critical threshold temperatures that might trigger them, there is the potential for additional risks at higher levels of global warming.

Another major source of uncertainty relates to melt-water contributions from snow and glacial ice. Miller and Rees (2011) and ICIMOD (2011) report that glacial melt currently accounts for different levels of river flow in different basins. However, with higher temperatures from warming, there is the potential for higher glacial melt water flows. A number of studies have looked at effects of temperature increases and the effects on glaciers/deglaciation (Rees et al., 2004; Chaulagain, 2006; Chaulagain, 2007). Rees et al. (2004) looked at the Hindu Kush Himalaya and reported that effects will vary strongly across different catchments and regions. Highly glaciated catchments, where melt-water contributes significantly to the runoff, appeared to be the most vulnerable to deglaciation. Climate change potentially could increase river flows in the short-term, because of enhancing glacier and snow melt, but in the longer-term, river flows might reduce as the volume of ice available for melting diminishes. These effects add a further layer of uncertainty to the results above and highlight the need for enhanced monitoring and research.

It is highlighted that the effects of glacial melt-water are not factored into the later impact assessments, and this uncertainty is also considered in interpreting subsequent impact results.

Overall Uncertainty

It is clear that uncertainty has important implications for the overall impacts in this study, and the interpretation of the results and findings. This is particularly important as the detailed modelling has only been able to use one RCM simulation.

First, it means that in interpreting the impact results (for one model) the comparison of other alternative climate model outputs - and the implications on results - need to be considered. This is particularly important in the context of changes in precipitation and river flow.

Second, in terms of adaptation, it emphasises the need to consider responses that address this uncertainty (rather than responding to central projections). This leads to iterative strategies to prepare for uncertain futures, focusing on resilience and robustness, rather than using uncertainty as a reason for inaction.

Finally, for the future it reinforces the need to develop multi-model climate model simulations for Nepal, to advance research and monitoring, and to work on the communication of these results, so as to ensure that this uncertainty is not used as a reason for inaction.

5.7. Socio-Economic Data and Sector Projections for Nepal

In considering future vulnerability to climate change, and adaptation responses, a critical step is to consider how socio-economic development might change Nepal over future decades. This is important because these socio-economic changes - such as population growth, the size of the economy and land-use development - will affect future vulnerability, impacts and adaptation. As an example, future population growth will increase demand for water and for natural resources, and rising levels of assets will increase the potential exposure to future extremes.

Previous studies show that these future non-climate drivers are as important as climate change in determining future economic costs (noting that failure to take future changes into account assumes that future climate change will take place in a world similar to that of today). There is also a need to consider how development itself will change future vulnerability, impacts and adaptation. The current and proposed policies and development plans of Nepal will influence future baselines at the national and sectoral levels. In many cases development will decrease the vulnerability to climate change (though this is not always the case). At the same time, climate change might actually affect wider development objectives, thus these policies themselves maybe at risk from changing climate trends and future climate change. There is, therefore, a need to analyse these existing policies in relation to climate resilience (see work-stream 2).

The study has examined some of these socio-economic trends, building them into the analysis where possible. One of the strongest socio-economic trends is future population growth. The population of Nepal has been rising rapidly, growing from 12 million in 1970 to around 30 million currently (CBS, 2012). Future projections indicate an increase in population to around 35 million by 2020, 40 million by 2030, 43 million by 2040 and 46 million by 2050 (UN, 2012), noting the rate of increase is projected to slow significantly. This growth will increase demand on land-use, natural resources and water.

The majority of the population (83%) is currently rural, and mainly relies on agriculture for their livelihoods. However, there have been strong urbanisation trends in recent years and the urban population is expected to increase to over 20% (to around 7 million people) by 2020 (UN, 2012).

The other key socio-economic driver relates to the economy and economic growth. There are short-term national development goals within the Government's Three year Plan (TYP) (2010/11-2012/13). This aims to increase the economic growth rate up to 5.5%, with agriculture at 4% and other sectors at 6.4%. The TYP also has introduced the concept of climate resilient planning, particularly in the policy and strategy of infrastructure projects (promoting green development, making development activities climate-friendly, mitigating the adverse impacts of climate change, and promoting adaptation). More recently, there has been a significant increase in overseas remittances and it is likely to increase further in the future if the present trend continues.

The Nepal Development Vision (2030) set out the longer-term aspiration for Nepal becoming a middle income country over the next decade and an upper middle-income country by 2030. This foresees high average annual GDP growth rate (9% during the next decade, and then increasing to 10% during the following decade), with a structural shift that makes electricity, gas and water one of the prominent sectors, and a key driver for growth from the production of hydro-power, as shown in the Figure below. The focus on electricity exports means that any effect of climate change on hydro-electricity generation will affect growth potential. There is an anticipated move away from the current dominance of agriculture, reducing from the current 35% to 21% by 2030. Nonetheless, the agricultural sector is still anticipated to drive growth forward, with irrigation as one of the drivers, thus again, there is a strong linkage with climate and other drivers. It is also noted that agricultural production fluctuates strongly between years, in part due to the influence of the climate.

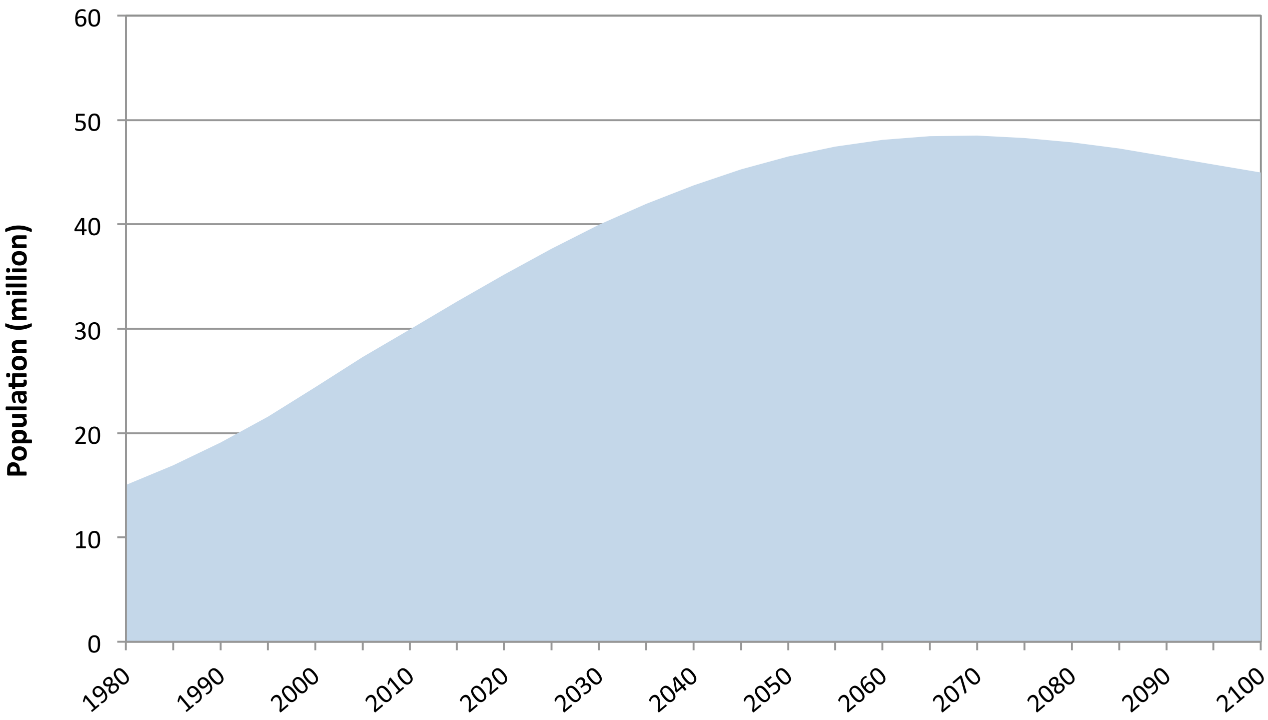


Figure 5.9. Population projection to 2100

Source: UN Population Projections.

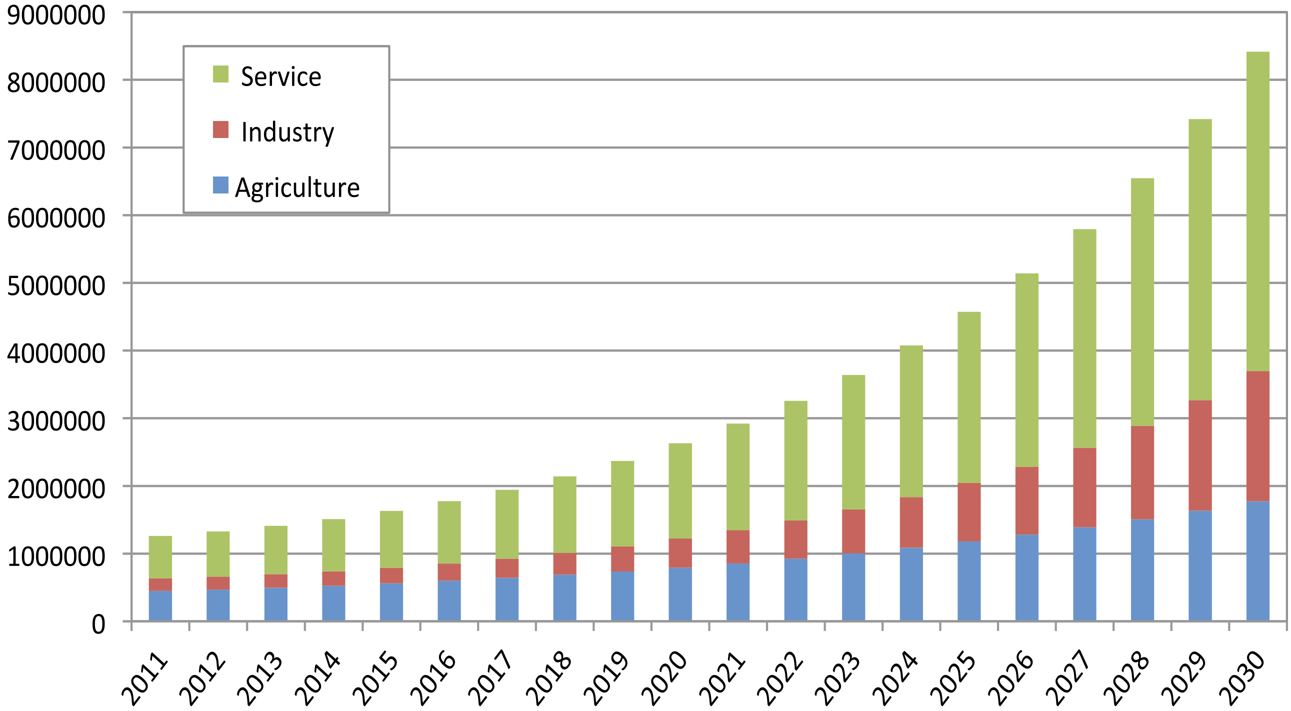


Figure 5.10. Real GDP growth and sector split to 2030.

Source: Nepal Development Vision, 2030.

Detailed analysis was also made of sectoral plans, detailed in work-stream 2, and of long-term sector plans in key areas such as hydro-electric generation, considering demand and system capacity. In the longer-term, the rates of GDP growth are more uncertain. The previous information for Nepal from the SRES A1 scenario is available[7]. This implies similar levels of GDP increase between 2010 and 2030 as above, and just under a further doubling (in total GDP) by 2050.

[7] The population and GDP components of the SRES scenarios have been downscaled to country and grid level (0.25°); this data can be found at: http://ciesin.columbia.edu/datasets/downscaled/.

6 The Risks to Current Plans over the Short-Medium Term in Nepal (Work-stream 2)

Key Summary Points:

- Work-stream 2 looks at the risks from climate change to current development policies over the short-medium term in Nepal. This grounds the analysis of impacts and adaptation in the institutional structure of the Government of Nepal, and takes account of the existing programmes and policies in place. It also provides the baseline information to assess future mainstreaming needs and adaptation investment for the medium term, aligned to existing country development plans.
- The analysis has undertaken an investment and financial flow analysis, a form of Public Financial Management (PFM) assessment. It looks at the current and future (planned) investment in each of the three sectors of interest. This analyses current baseline 'on-budget' programmes and 'off-budget' activities funded by donors, the private sector, etc. This has been undertaken for hydro-electricity, water-induced disasters, and agriculture (including agricultural development and irrigation) sectors.
- The analysis of current baseline investment includes the public (on-budget and off-budget) and private sectors. The analysis finds that the current investment in these sectors totals around US$1.8 billion/year, but this is dominated by agriculture. A future profile of investment from the present to 2030 has then been built up for each sector. For hydro-power, the total investment (including public sector, off budget and private sector) was projected to increase in real terms from the current US$390 million/year to US$1.1 billion/year by 2030, with a total investment of US$5 billion for the period 2014-2030 (discounted). For irrigation, investment is projected to increase from the current US$1.4 billion/year to US$3.8 billion/year by 2030, with a total PV investment of US$17 billion for the period 2014-2030. Finally, for water-induced disasters, investment is projected to increase from US$29 million/year currently (on river management, watershed conservation) to US$60 million/year by 2030, with a total PV investment of US$321 million for the period 2014-2030. This shows continued high investment and growth in the agricultural sector. It also shows a much higher increase in hydro-power investment. The investment in water-induced disasters is lower, reflecting the dominance of the state and development assistance funding.
- The analysis has then reviewed the existing policies and plans in place, to assess the risks of climate change in these areas, and to assess whether climate resilience is already being mainstreamed. This climate risk screening assesses the level of 'climate readiness' of the current policy framework and identifies opportunities for mainstreaming.
- A key finding is that the Government of Nepal is already mainstreaming climate change considerations into its national level planning frameworks such as the Three Year Plan, and has developed a strong package for supporting climate change strategies (NAPA, LAPA, SPCR, and Climate Change Policy). However, at a sector level, climate change issues are less well covered, and objectives and actions are not often framed in the context of climate change (though more recent strategy documents do explicitly consider and address climate change impacts). Progress has been particularly strong in the agricultural

sector, where the Priority Framework for Action, and the draft Agricultural Development Strategy, both put climate resilience at their core. In other sectors (hydro-power and water-induced disasters), less progress has been made in updating policy to fully reflect current and especially future risks. However, many of the policies and programmes relevant to the water sector implicitly promote activities that will support resilience, and this offers a solid basis for the reframing of existing legislation. The analysis also identifies areas where it would be useful to strengthen adaptation mainstreaming.

- The study has also built on the recent analysis on the level of resilience mainstreaming in the GON budget. This identified approximately NRs. 7bn worth of activities as 'reducing the negative impacts of climate change' primarily in the water-induced disaster and agricultural development programmes. However, the analysis here identifies policy gaps and mainstreaming priorities. These have been carried forward to the analysis of adaptation needs and the analysis of an overall adaptation investment analysis.

6.1. Introduction

The second major work stream considers future development plans, looking at the potential risks of climate change, and building the information to identify the potential adaptation responses. To do this, it has undertaken an Investment and Financial Flow Analysis (IFF). This work-stream grounds the analysis of impacts and adaptation in the existing institutional and existing programmatic structure of the Government, and it also builds a baseline that takes account of the large existing programmes already operating in Nepal to address climate risks.

The IFF approach takes into account potential resilience and adaptation type activities already under implementation using a form of Public Financial Management (PFM) assessment. This is particularly relevant for water and agriculture sectors, where there is a high degree of overlap between good development and climate resilience. The study has first built a baseline of investment and financial flows in relevant sectors (agriculture, hydro-electricity and disaster risk management). It has then undertaken a risk screening of existing major policies and programmes, building on the Government's assessment of climate mainstreaming. This information has been used (in Chapter 8) to subsequently construct an additional sectoral adaptation and investment scenario.

It should be noted that both the baseline and the adaptation scenarios presented here do not represent official commitments by the Government of Nepal or other stakeholders towards investment in the agriculture or water-related sectors. Rather they are 'indicative' high level scenarios of two potential investment pathways for Nepal to 2030. More detailed investment planning processes will be required in the main programme areas to develop specific costed proposals as sector adaptation mechanisms evolve.

6.2. Current Baseline Analysis

The investment baseline covers 'on-budget' programmes and activities financed through the budget framework of the Ministry of Finance. It also provides estimates for 'off-budget' activities financed by NGOs and other donors directly to beneficiaries, together with private sector investments. For on-budget activities, the analysis has been carried out for the government budgets in the four main relevant Ministries, i.e. Ministry of Energy (MoE), Ministry of Agricultural Development (MoAD), Ministry of Irrigation (MoI) and Ministry of Science, Technology and Environment (MoSTE). The baseline profile is based upon the best available programme and project data provided through the MoF budget planning and reporting processes. The share of off-budget and private sector investment are estimated on the basis of MoF reporting, supported by expert opinion and discussions with GoN officials. The projections assume steady growth in the relevant budgets based on assumption set out in publically available strategies (e.g. 2050 AD Water and Energy Vision). However, actual growth will vary.

Data was taken from the Estimates of Expenditure (GoN, 2013) published in July 2013 (the Red Book) covering a three years period from 2011-2014. The budgets for the four Ministries above include approximately 140 department and programme line budgets, and include both recurrent (operational) as well as capital (recurrent) costs. For each programme, we have allocated a percentage of the budget for FY 11/12-13/14 to each of the three major themes (hydro-electricity, water-induced disasters and agriculture).

In terms of funding profile (source of funds), the type of expenditure varies by sector. Figure 6.1 presents the average funding profile for FY 2013. Approximately 70% of the relevant Ministry budgets are financed from national revenues, with 25% financed by foreign grant and 5% through foreign loans. MoSTE receives a much higher percentage of grant funding compared to other ministries, with Ministry of Irrigation receiving the largest percentage of loans.

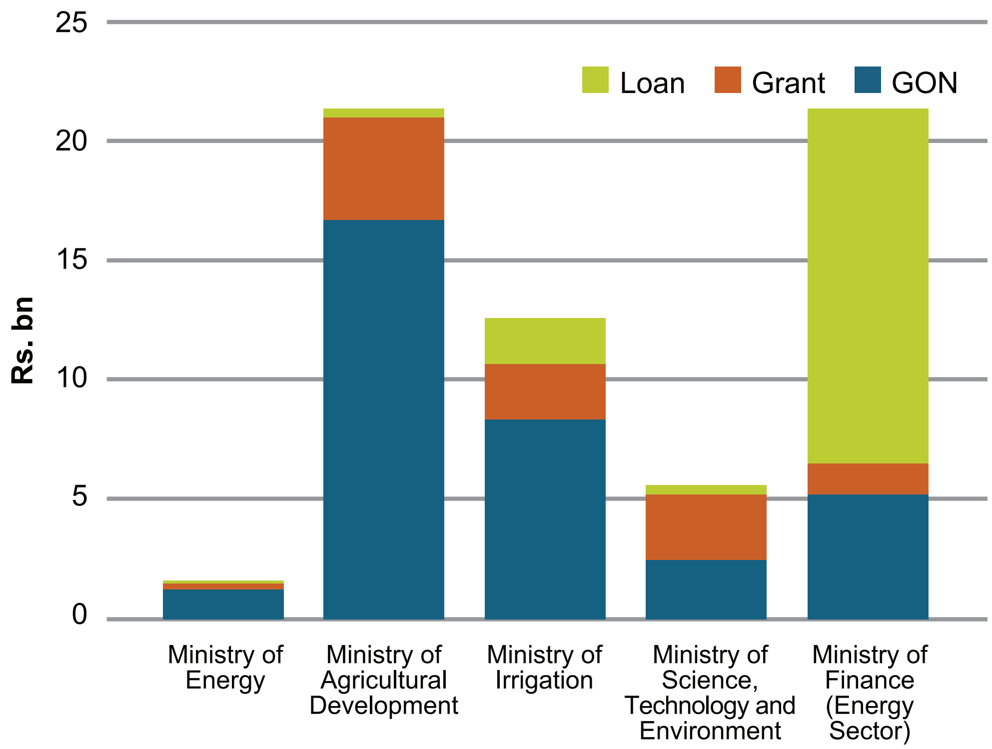


Figure 6.1. Source of Finance by Ministry 2013-14 (Rs. bn.)

Source: Project Team.

6.3. Future Baseline Investment

The analysis of future investment has considered the on-budget, off-budget and private sector investment in the three areas of interest. On the basis of current expenditure data, the baseline was used to estimate the future trajectory of public sector allocation for the three sectors over the period from 2014 to 2030. These used specific capital growth assumptions for the sector which can be found in the 2050 AD vision published by the Water and Energy Commission.

Table 6.1. Expected Sector Capital Investment Growth rates (2011-2030)

	2011-20	2021-30
Hydro-electricity (combined policy scenario)	19.6% (5.5%)*	5.2%
Irrigation (central scenario)	5.1%	4.5%
Water Supply	1.9%	1.6%

Source: Water and Energy Commission 2050 AD Vision.

*Based on current investment levels, the assumptions of a 19.6% growth rate in hydro-power investment by 2020 seems optimistic. Hence, for the purpose of modelling, we assume a more conservative 5.5% growth rate, reflecting expected national GDP growth. This brings expected investment in line with the hydro-power modelling assumptions set out in Chapter 7 on impacts, although the latter focuses on domestic electricity demand.

Currently, around 23% of programmatic funds are disbursed directly by donors on projects and are not accounted for within the official budget (Red Book). This provides the basis for the off-budget contribution for agriculture and irrigation. Off-budget spend on hydro-power and water based disasters is estimated to be lower due to the capital intensive nature of these projects and 10% is used as a planning assumption. However, off-budget funds are declining as a percentage of overall development spending, thus it has been assumed that off-budget contribution will decline across all three sectors as Nepal reaches developing country status. We therefore assume that only 5% of programmatic funds disbursed off-budget by 2030, as donor activities are increasingly mainstreamed through national budgets.

Finally, the private sector is expected to play an increasingly prominent role in many sectors of Nepal's economy, and is already an equal or majority investor in energy and agricultural sectors. Private sector contribution is expected to grow over time in line with GoN commitments to attract private sector finance to productive areas of the economy. Following discussions with the NPC and sector planning ministries, it has been assumed that hydropower will have approximately equal public/private share, whilst private investment in agriculture is approximately 70% of the total investment. For both hydropower and agriculture, the share of public investment is scheduled to decrease over time in line with the promotion of private investment. Prevention of water-induced disasters is considered a public good, and will be financed exclusively through the GoN budget without private sector participation.

The results are summarised below. A 10% discount rate was used in estimating total present values for the period 2014-2030.

The total allocation - including public sector, off-budget and private sector contributions - to hydropower related activities in 2013/4 was US$390 million. Under the baseline, this is expected to increase in real terms to US$1.1 billion/year by 2030, with a total investment of US$5 billion for the period 2014-2030 (discounted), as shown in Figure 6.2. The current expenditure is estimated to split 50% each for the public and private sector, with the share of public sector support declining towards 40% as the use of capital markets increases.

For irrigation, including budget, off-budget and private sector investment, we estimate that approximately US$1.4 billion will be invested in the agriculture and irrigation sector in 2013-14, of which, the private sector represents approximately 70%. Funds allocated through the GoN budget represent approximately US$327 million in 2013. Under a baseline scenario, the total annual investment is projected to increase to US$3.8 billion/year by 2030, with a total investment of US$17 billion for the period 2014-2030 (discounted), shown in Figure 6.2. On-budget expenditure is estimated to reach US$720 million by 2030, representing a decline in the share of investment from the public sector from 30% to 20% over the period.

Finally, for water-induced disasters, the 2013 Budget indicates a total amount of US$26 million for river training, landslide management and watershed conservation projects. Including on-and off-budget investment, we estimate that approximately US$29 million will be invested to address water-induced disasters in 2013-14. We assume that investment in disaster prevention will remain a public good, funded mainly by the state but also with some off-budget donor support, and without any private sector contribution. Under a baseline scenario, total annual investment is projected to increase to US$60 million/year by 2030, with the increase being met primarily from public funds, as shown in Figure 6.2. This constitutes a total investment of US$321 million for the period from 2014 to 2030 (discounted).

The resulting baseline projections in each of the three areas are presented in Figure 6.2, allowing a comparison of future investment between the three areas (in total, and split by the source of finance between on-budget, off-budget and private funds). This shows the rising level of baseline investment for the three areas. Analysis of the Figure shows that current investment is dominated by agriculture, but hydro-power will become increasingly important in future years.

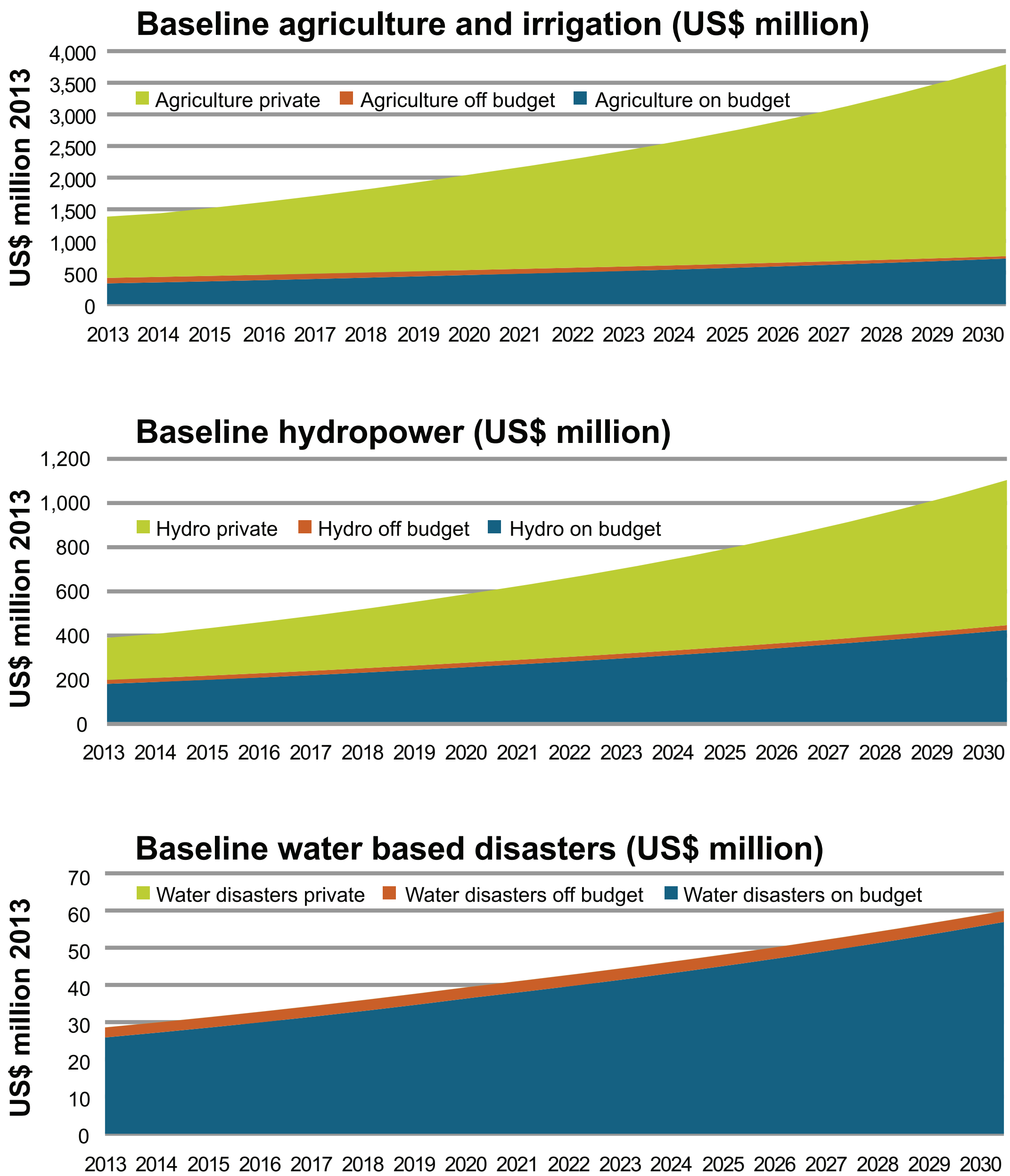


Figure 6.2. Baseline by sector (US$million 2013)

Source: Project Team.

6.4. Policy and Programme Risk Screening

The next step in work-stream 2 has been to review the existing policies and plans in place, to assess whether climate resilience is already being mainstreamed (or not). The aim of this climate risk screening is to assess the possible risk of the programme to climate change, and then assess the level of 'climate readiness' of the current policy framework and to identify existing resilience building or opportunities for mainstreaming.

This is important because the GoN is currently engaged in a number of activities, and has a number of programmes that are relevant for early resilience. Many of these activities involve early adaptation options, i.e. that are addressing the current adaptation deficit, and which include many of the options identified in adaptation studies in Nepal. The study has therefore mapped the existing policy landscape across the Government, and then undertaken a climate risk screening assessment to see whether they include existing resilience relevant activities or explicit climate change components. This is presented for each sector and summarised below. It is noted that the review was comprehensive when undertaken, but that it is a snapshot at a particular time, and policies will continue to emerge (and be updated).

National Development Strategies

The preceding Three Year Plan (TYP 2010/11-2012/13) - prepared by the National Planning Commission (NPC) - sets out a strategic framework based on the existing policies, priorities and potential resources available (it is noted that since the review, a new Interim Plan has been published in July 2013 for the period of 2013/14-2015). The TYP has climate change considerations mainstreamed into its macro-planning framework and the issue is given prominence throughout the document, with risks clearly highlighted. Climate change adaptation action plans are identified as priority actions for a range of sectors (forestry, industry, local government and health). For the water sector, consideration is given to the potential impacts of climate change on potable water availability, agricultural irrigation, hydro-power and disaster risk management. Specific responses are identified under the 'Environment' section, with focus placed on development and implementation of the National Adaptation Plan of Action (NAPA), and development of climate research capacity. There is limited detail in how adaptation will be mainstreamed in specific subsectors.

In the intervening period, the NAPA (2010) and the Climate Change Policy (2011) have been enacted. The NAPA addresses water related sectors through the promotion of community-based adaptation and the integrated management of agriculture and water. GLOF monitoring and community-based disaster risk management are other water related priority actions. The Climate Change Policy sets out the risks associated with climate change and proposes a range of priority thematic areas. For the water sector, these include improved systems for glacial lake monitoring, and the development of early warning systems for water-induced disasters. Nepal has also prepared Local Adaptation Plan of Actions (LAPAs) supporting water based resilience at a community level.

A strategic program for climate resilience (SPCR 2011) under PPCR has also been prepared. This will work alongside other national climate planning documents. It has water related components addressing water-induced disasters, water supply and irrigation in mountain areas and climate proofing hydro-power facilities.

It is stressed that the recent Thirteenth Plan (2013/14- 2015/16) - prepared by the National Planning Commission (NPC) - has expressed commitment to promote green economy and consequently adopted a macro level strategy to implement development programmes following the principle of climate compatible development.

Agriculture (including Irrigation)

The Agricultural sector is overseen by a broad range of policies and strategies, each addressing a particular aspect (e.g. seeds, fertiliser, coffee, business promotion etc.). The GoN is currently considering a new comprehensive

Agriculture Development Strategy though this remains in draft form at the time of writing. The Ministry of Agriculture and Cooperatives has prepared a plan of action for climate change adaptation and disaster preparedness in agriculture. It emphasised strengthening institutional and technical capacity, risk and vulnerability assessment, development and transfer of technology, awareness raising, and disaster preparedness.

Agricultural Development Strategy

The MoAD has prepared a new Agricultural Development Strategy (ADS), which is awaiting approval from the Cabinet. To support this Strategy, a number of planning documents have been produced, including 'Vision and Assessment' documents in 2012. These documents have been supported by a number of integrated agriculture and water resource (IAWR) studies. A review of these documents indicates that climate change is well mainstreamed into the ADS design considerations. The vision identifies climate change as a key influencing trend. The documents clearly set out projected climate impacts and recognise threats from climate change, including shifting of agro-ecological zones, changing incidence of pests and diseases, and changes in productivity and seasonality of agricultural production. The documents set out the opportunities for climate finance and the needs of preparedness for disaster risk management such as early warning and insurance.

Priority Framework for Action: Climate Change Adaptation and Disaster Risk Management in Agriculture (2011)

This planning framework was prepared by FAO and the Ministry of Agriculture and Cooperatives in 2011. It takes the priorities of the NAPA and the National Strategy for Disaster Risk Management (NSDRM) and maps them on to the work of the Ministry. The historic climate impacts on agriculture are set out, together with future projections of climate change and the sector implications. Key water related risks relate to provision of irrigation water, and flood damages. A gap analysis is undertaken on existing plans and strategies, and a framework is set out, including a number of priority actions and institutional mechanisms. These include institutional capacity for adaptation, enhanced risk monitoring, improving awareness, technical options and disaster preparedness.

National Agricultural Policy (2004)

The National Agricultural Policy (NAP), adopted in 2004, set out the broad framework for the promotion of more effective agricultural practices to address food security issues. There is no reference to climate change in the document, but there is some mention of the impacts of drought, disease and natural disasters on agriculture. Some of the policies and measures proposed will build resilience against current climate risk. These include the creation of natural hazard monitoring systems, the promotion of small scale irrigation systems, the development of safety nets for subsistence farmers and the extension of livestock insurance programmes.

Irrigation Policy (2003)

The policy is formulated with the objective of promoting ground and surface water based irrigation systems along with new/non-conventional irrigation systems such as rain water harvesting, pond irrigation, sprinkler irrigation, drip irrigation and treadle pump irrigation. In Nepal, the irrigation systems developed so far are limited to run-of-river systems. To make the system effective for round-the-year irrigation, it is necessary to develop storage so that the problem of low flow of rivers during the winter season can be mitigated. The policy aims to develop irrigation facility for the achievement of following objectives: a) to avail round the year irrigation facility through effective management of existing water resources; b) to develop the institutional capacity of water users for sustainable management of existing systems; and c) to enhance knowledge, skills and institutional working capability of technical human resources, water users and NGOs relating to development of irrigation sector. It is highlighted that a new irrigation policy is in the approval process, and this will update the current policy above.

Water Policy: Cross Cutting

There are two key policy documents that cover the water sector. The policies summarised below cover a full range of water-related issues, including water-induced disasters, agricultural irrigation and hydro-power.

Water Resources Strategy Nepal (2002)

The 2002 Water Resources Strategy Nepal is a cross cutting document which sets out a comprehensive approach to water planning. It covers water supply and sanitation (WSS), irrigation and hydro-power, as well as a range of institutional, legal and environmental issues. The strategy sets out a short (5 year), medium (15 year) and long term (25 year) vision. Many of the issues addressed and activities proposed are 'climate resilience' relevant, but not explicitly labelled as such. These include addressing water induced disasters and GLOFs, upgrading the flood forecasting system and hydro-meteorological network, mapping disaster zones and preparing early warning systems, improving watershed management, and developing more efficient irrigation and hydro-power infrastructure. However, there is little discussion of climatic trends or future projections, and only one action is explicitly labelled as climate change - namely the establishment of a Himalayan Climate Change Study Centre under the Department of Hydrology and Meteorology.

National Water Plan (2005)

The National Water Plan (NWP) acts as the implementation strategy for the NWS. The NWP recognises the objectives of the NWS and lays down short-, medium- and long-term action plans for the water resources sector, including investments and human resource development. Again, climate resilience related objectives are set out, such as mitigating the impact of water-induced disasters, and improving watershed management. However, the frequency and severity of these disasters are ascribed primarily to zoning and planning issues, and climate change is not explicitly considered within the document (it is only implicitly discussed in relation to promoting research and studies on ecological water requirements, water quality, functioning of glacial lakes and existing dam structure). Only the establishment of the Himalayan Climate Change Study Centre can be identified as an explicit climate change activity. Since 2005, there have been a number of government-led and sponsored studies looking at the impacts of climate change on the water sector. The most comprehensive of these is the 2011 study 'Water Resources of Nepal in the Context of Climate Change', which assesses the relationships for different sectors, including natural disasters, hydro-power and agricultural irrigation. As yet, none of these have been used to update the policy.

Hydro-electric Power

The following section summarises out the main policy areas governing the water in relation to hydropower sector.

Rural Energy Policy (2006)

The Rural Energy Policy (2006) sets out the approach to delivering energy to off grid communities through a range of technologies such as biogas, biomass, solar, and productive energies. These technologies also include micro and small hydropower. The policy does not explicitly recognise the impact of climate change on hydro-production, nor does it highlight the potential benefits of rural energy in increasing community level resilience.

Hydro-power Development Policy (2001)

The main policy framework governing the sector remains the Hydro-power Development Policy (2001). The policy identifies 42,000 MW of technically and financially realisable capacity. The policy recognises a range of benefits, which include the downstream benefits of flood control. While primarily targeted at medium and large projects, the Policy also sets out the basis for mini and micro-hydro (<100kw) projects. The Policy does not have any reference to the potential impacts of climate change on hydrological flows or competing water demands, but does make provision that if hydrological conditions are more adverse than anticipated when the license was granted, the licence term may be extended by up to 5 years as compensation. There have been a number of further planning documents issued since 2006. For example, the WECS produced a review of documents prepared for 'Nepal's Long Term Vision on Water Resources and Energy Sectors 2050 AD', but this also does not explicitly make reference to climate change.

Water-induced disasters

The response to Water-induced disasters is governed by two key policy documents:

Water Induced Disaster Management Policy (2006)

The Water Induced Disaster Management Policy (WIDMP) sets out the broad approach to addressing floods and GLOF risks. It is a short document, addressing five thematic areas: emergency response, reduction of water-induced disasters, conservation of natural resources, use of riverbank and flood affected areas, and institutional provision and development. While many of the activities areas proposed address obvious climate related issues and build resilience, climate change is not explicitly mentioned in the document.

National Strategy for Disaster Risk Management in Nepal (2008)

The National Strategy for Disaster Risk Management in Nepal (NSDRMN) is the main policy document setting out the approach to a broad range of natural disasters. These include water based as well as earthquake and health disasters. The Strategy sets out a comprehensive review of historic disasters and institutional responses.

GLOFs are identified as a hazard that will be exacerbated by climate change. In terms of responses, the strategy promotes the use of early warning system (EWS) and monitoring systems to help understand the risks between climate change and natural disasters under Priority Action 2. Climate change is also referenced in relation to the knowledge management plans (Priority Action 3). The Strategy recognises the lack of climate change mainstreaming under Priority Action 4. Suggestions are made for mainstreaming DRR and climate considerations into sector plans, including agriculture.

Overall analysis

A summary of the risk screening is presented below. A key finding is that the Government of Nepal is already mainstreaming climate change considerations into its national level planning frameworks such as the Three Year Plan, and has developed a strong package of climate change strategies (NAPA, LAPA, SPCR, and Climate Change Policy). However, at a sector level, climate change issues are less well covered, with objectives and actions often not framed in the context of climate change.

More recently, a number of strategy documents have been produced that explicitly consider and address climate change impacts. Progress has been particularly strong in the agricultural sector, where the Priority Framework for Action, and the Agricultural Development Strategy, both put climate resilience at their core. In other sectors (hydro-power and water-induced disasters), less progress has been made in updating policy to fully reflect both current and especially future risks. As Figure 6.3 suggests, many of the policies and programmes relevant to the sector implicitly promote activities that will support resilience in the water sector, and this offers a solid basis for the reframing of existing legislation going forward. The figure also identifies priority areas for strengthening, or more explicitly recognising climate considerations in the future.

Sector	Policy	Explicit climate change objectives	Implicit climate resilience benefits
National Development	National Three Year Plan (2010–2013)		
Water cross-cutting	National Water Strategy (2002)		
	National Water Plan (2005)		
Agriculture and irrigation	Draft Agriculture Development Strategy (2012)		
	Climate Change Adaptation: Priority Framework for Action (2011)		
	National Agricultural Policy (2004)		
	Irrigation Policy (2003)		
Hydropower	Rural Energy Policy (2006)		
	Hydropower Development Policy (2001)		
Water disasters	Water Induced Disaster Management Policy (2006)		
	National Strategy for Disaster Risk Management in Nepal (2008)		

Explicit climate resilience objectives

- Does not explicitly recognise climate risks in policy development
- Explicitly recognises current climate risks to policy development
- Explicitly recognises future climate change with policy response

Implicit climate resilience benefits

- Activities deliver minimal or no climate resilience benefits
- Activities likely to build resilience to current climate risks
- Activities provide resilience for increased risk scenarios in future

Figure 6.3. Assessment of Climate Readiness of Key Policies and Strategies

Source: Project Team.

6.5. Existing Resilience Investment

The information above was further extended to look at the proportion of the GoN budget which is already allocated to activities that will support or increase resilience to climate change in the existing sectors. It is important to take this investment into account for looking at baseline and future risks from climate change, and to develop the additional (or marginal) investment needed for adaptation.

The recent budget (2013-14) included analysis on the level of resilience mainstreaming in the GoN budget. Approximately NRs. 7bn of activities were identified as 'reducing the negative impacts of climate change'. Of these, the following areas of climate resilience spending were identified:

- Ministry of Agricultural Development - Rs. 1.8bn. This represented approximately 32% of the total annual budget for the Ministry.
- MoSTE - Rs. 4.8bn. This represented 87% of the total annual budget.
- No activities were identified in the Ministry of Irrigation or the Ministry of Energy.

Table 6.2. Share of climate relevant budget (Rs. bn)

	Highly relevant	Relevant	Not relevant
Ministry of Energy	0.9 (55%)	0.0 (0%)	0.7 (45%)
Ministry of Agriculture Development	1.0 (5%)	10.2 (47%)	10.3 (48%)
Ministry of Irrigation	4.8 (38%)	4.9 (39%)	2.9 (23%)

Source: GoN Budget 2013-14.

The baseline investment, policy review and existing resilience analysis were used in the subsequent analysis of adaptation, in combination with the results from work-stream 3, to build up an adaptation mainstreaming scenario and investment profile. This is presented in Chapter 8.

7 Impacts of Future Climate Change (Work-stream 3)

Key Summary Points:

- The final work-stream assesses the future impacts of climate change, working with downscaled climate model projections and sector models. The analysis in the agricultural sector focused on the key crops in Nepal, i.e. maize, wheat and rice, using the DSSAT crop model. The results show a strongly differentiated pattern over time and across the country, with potentially high negative impacts from climate change in the Terai in later years, but a varied pattern in the Hills and Mountains (including potentially high benefits). The study has valued these changes to provide analysis of the overall change in total production. The overall finding is that in the 2030s, there is a projected net increase in production with economic benefits, but by the 2070s, there is a decrease in most crops and high net economic impacts, estimated at US$140 million/year (undiscounted), which is equivalent to around 0.8% of current annual GDP. In extreme years the effects of climate change will, however, be much more severe. The study has also considered the climate model uncertainty, noting large differences in key variables (rainfall trends and variability) between different models, which leads to a range of results including more positive outcomes but also possible severe impacts. A number of other potential impacts are identified including increased flooding, increased soil erosion and the changing range/ prevalence of pests/disease.
- The analysis of the future impacts of climate change on hydroelectric power combined hydrological model runs with a hydro-electricity optimisation system (VALORAGUA and WASP), to consider the changes in river flows and energy generated. There were large differences found in the projections of different climate models and the study, therefore, compared two different data sets. The first model projected lower dry season flows and lower energy availability. The additional capacity needed to meet future demand under this scenario (2800 MW by 2050) was estimated at an additional generation expansion costs of US$2.6 billion (present value) for the period through to 2050. This scenario also leads to increased level of thermal plant on the system, increasing GHG emissions. However, the second model, which projects higher river flows in the dry and wet seasons, led to increased energy availability and avoided the need for additional plant, thus leading to a reduction of generation expansion costs of - US$170 million (present value) over the period to 2050 compared to the baseline (i.e. a benefit). The findings indicate that climate change could potentially have a major impact on future generation and investment, but the uncertainty necessitates an iterative response. Additional uncertainty is added by the impacts of glacial melt water, and risks of high flows and GLOFs.
- The analysis of the impacts of climate change on water-induced disasters used detailed hydrological data to assess the future impacts. It assessed the change in the frequency and intensity of high river flows, and thus the risk and impacts of flooding (i.e. the shift in the probability-loss relationship). The increase varies with the river catchment, climate and hydrological model, but high flows were found to increase by 20%-100% by mid-century (2040s) due to climate change. At the same time, climate change will increase the frequency of high flow (flood) events. The return period for a 1-in-10 year

event was found to reduce to 1-in-5 years (or less) and the risks of very major events, such as a 1-in-100 year event to once every 10-30 years with climate change. An analysis of the potential economic impact of these changes was undertaken, using analysis of historical damages and the changes from climate change. The central estimate of the direct economic cost of climate change is US$100 million to US$200 million/year by mid-century (equivalent annual damage, current prices, undiscounted), equivalent to 0.6% to 1.1% of current GDP. The total cost (including indirect and macro-economic costs) would likely be 25% to 100% higher. However, the full range across the projections is much larger, with an upper estimate of almost 3% equivalent of current GDP. The cost of these floods could also rise with growing population and assets at risk, though rising wealth should increase adaptive capacity and reduce future risk levels.

- Finally, the study has looked at the wider economic costs from climate change. An analysis of input-output tables for Nepal has identified the main linkages (forwards and backwards) and their relative climate risks. These show potentially important linkages that would increase the impacts above.
- Overall, the study concludes that there are potentially high economic costs from climate change in Nepal. The direct costs from the three sectors considered could be equivalent 2% to 3% of current GDP by mid-century (static assumptions), though more modest and more extreme outcomes are also possible.

7.1. Introduction

The final work-stream (3) assesses the impacts of future climate change on key sectors in Nepal. This focuses on the medium-and long-term impacts and economic costs (to mid-century and beyond). These future impacts have been considered using scenario-based impact assessment (Carter et al., 2007), which uses climate model projections as an input to sectoral impact models.

It is stressed that the application of these impact assessment models in Nepal is challenging, because of the strong differences in climate across the elevation gradient of the country (and thus large regional differences in impacts) and because of the complexity of the existing climate, which is difficult to capture even with bias corrected regional downscaled models. Further more, as highlighted in Chapter 5, there is considerable uncertainty in the future changes projected across different future emission scenarios and individual climate model outputs, which needs to be considered when interpreting the results. Nonetheless, it is important to investigate these potential impacts, as they provide policy-relevant information on the major risks and the potential scale of future impacts and adaptation, as long as these uncertainties are taken into account.

At the same time, it is highlighted that there are a wide range of potential impacts to these sectors, not all of which are covered in the models. It is important that all the risks are considered, especially when considering overall risk analysis and for holistic adaptation responses. Therefore to complement the quantified modelling analysis, two sets of additional discussion are included for each sector: the first on the climate model uncertainty analysis and the potential impacts on the results and the second on the additional impacts and risks that are not captured in these impact models.

7.2. The Impacts of Future Climate Change on Agriculture

There is increasing evidence of the effects of climate change on agriculture, which indicates potentially large effects, particularly in developing countries (Rosenzweig and Parry 1994; Parry et al., 2005; Mendelsohn et al., 2006; Cline 2007; Easterling et al., 2007; Lobell et al., 2008). These effects involve many potential climate variables, which can impact directly and indirectly on many aspects of crop production, e.g. crop distribution, growth rates, development and flowering, maturity periods, etc. as well as wider agricultural supply and value chains. The main focus in the literature has been on the potential effects of climate change on productivity from higher temperatures, and changes in rainfall and rainfall variability. It is highlighted that these effects can be positive (such as CO_2 fertilization and from extended growing seasons in colder regions) as well as negative (e.g. low rainfall). However, there may also be additional effects due to changes in the length or timing of seasons, as well as increasing intensity or frequency of extremes (floods and droughts), changes in pests and diseases (range and prevalence/incidence), factors affecting soil conditions or soil erosion, and from other impacts on the value chain (e.g. on rural roads). These risks affect many types of potential actors and livelihoods, from farm-level (subsistence farmers) to agricultural imports/exports, noting that the overall effect on demand and prices is linked to regional and global demand and production, and the effects of climate change elsewhere.

To date, most studies on climate change and agriculture have focused on the analysis of climate change on crop productivity or farm incomes, with the two respective approaches used being crop models and Ricardian (econometric) analysis. Both of these have been applied in Nepal, and there is also a broader literature available on the future impacts of climate change in Nepal (Sherchand et al., 2007; Malla, 2008; Rai et al.; Pokhrel and Pandey, 2011; Nayava et al., 2011; Thapa and Joshi, 2010; Pant, 2011; Lama and Devkota, 2009; Bastakoti et al. 2011: PPCR, 2012). However, to date, no study has used detailed regional bias corrected climate model projections in crop models in Nepal, to provide an analysis at high level resolution for the country, and this was the focus chosen for this study. As highlighted in the method section (Chapter 3), this study has used the DSSAT model, a crop model (agronomic model) which assesses the soil-plant-atmosphere components for plant growth and yield, and can look at the effects of future climate change on crop productivity.

As highlighted in Chapter 2, agriculture is of vital importance for Nepal in terms of GDP and employment as well as rural livelihoods and food security. Rice is the main crop, followed by maize and wheat (in terms of area and production). The Terai region is generally the most productive and fertile area, though overall, the average productivity in Nepal is low compared to neighbouring countries. Some 3.1 million ha is cultivated (20% of the total area). The high proportion of rain-fed agriculture makes it highly sensitive to future changes in climate.

The study used the DSSAT model to analyse the effects of climate analysis on three major crops: rice, maize and wheat, analysing impacts for nine separate regions across Nepal (for eastern, central and western areas in each of the Terai, hills and mountains) – shown in Table 7.1. This covers the three broad agro-ecological zones (see Chapter 2) and also strong climatic differences from East to West. District level crop data for a period of 11 years (1990-2000) was used for the analysis which is sufficient for projection.

Table 7.1. Sample Districts by Region Used in the DSSAT Analysis

	West	Central	East
High mountains	Jumla	Mustang	Solukhumbu
Mid-hills	Surkhet	Lalitpur	Dhankuta
Terai	Banke	Rupendehi	Sunsari

The analysis was undertaken for a single regional climate model run-the PRECIS model output (based on the GCM Had-CM3) provided by IITM for the A1B scenario, looking at the change from temperature and precipitation from 1972 to 2070. The availability of the data on the yield of three major crops by research stations/outreach sites of NARC was very much limited and considered to be insufficient for this analysis. Hence, crop yield data of the districts for 10 years from 1991 to 2000 was taken from the publications of the Ministry of Agriculture and Cooperatives. Note that the analysis did not consider existing irrigation, as this data is not yet available on a sufficient resolution for inclusion in DSSAT. An analysis was also undertaken with and without CO_2, and for two future CO_2 concentrations, to explore the effects of CO_2 fertilisation.

Results

The first major crop considered in the analysis was rice. Rice is the most important crop in Nepal. It contributes nearly 20% to the agricultural GDP and provides more than 50% of the total calorie requirement of the Nepalese people. It is grown across some 1500 thousand ha and is the largest crop, by area, grown in Nepal. The total production of rice (with husk) is about 5 million tons with average productivity of 3.3 tons per hectare.

The analysis of the impacts of climate change on rice production is shown in Figure 7.1. This reveals interesting results, both in relation to the changing climate trends over time (such as temperature and long-term rainfall trends), but also in relation to the changing variability (of rainfall). Results are shown for the % change in yield in the 2030s and 2070s (Figure 7.1, top), relative to the 2010s (current). Note that most rice is currently produced in the Terai, so changes in production in this region are especially important in terms of national production, as shown in Figure 7.1 (bottom).

The results show a complex mix of increases and decreases in yield which varies over time (2030s and 2070s) and by location (east to west/Terai to Mountains).

- In the Terai, the short-term analysis (2030s) indicates an increase in yields. However, in the longer-term (2070s) these changes are reversed and there are reductions in rice yields, up to 10%. This is due to a combination of lower rainfall and higher temperature during the growing season.
- In the Hill region, there is generally a more positive trend with productivity increases in the short-term (2030s), especially in the western district, driven by increased temperature during the growing season. In the longer-term (2070s), the pattern is more mixed: while the positive trend continues in the west, there is a decline in productivity growth for the east (almost 20%).
- In the mountain region, there is a long-term trend of increasing yield in the short and the long-term, due to rising temperatures during the growing season increasing the low levels of current productivity in these areas.

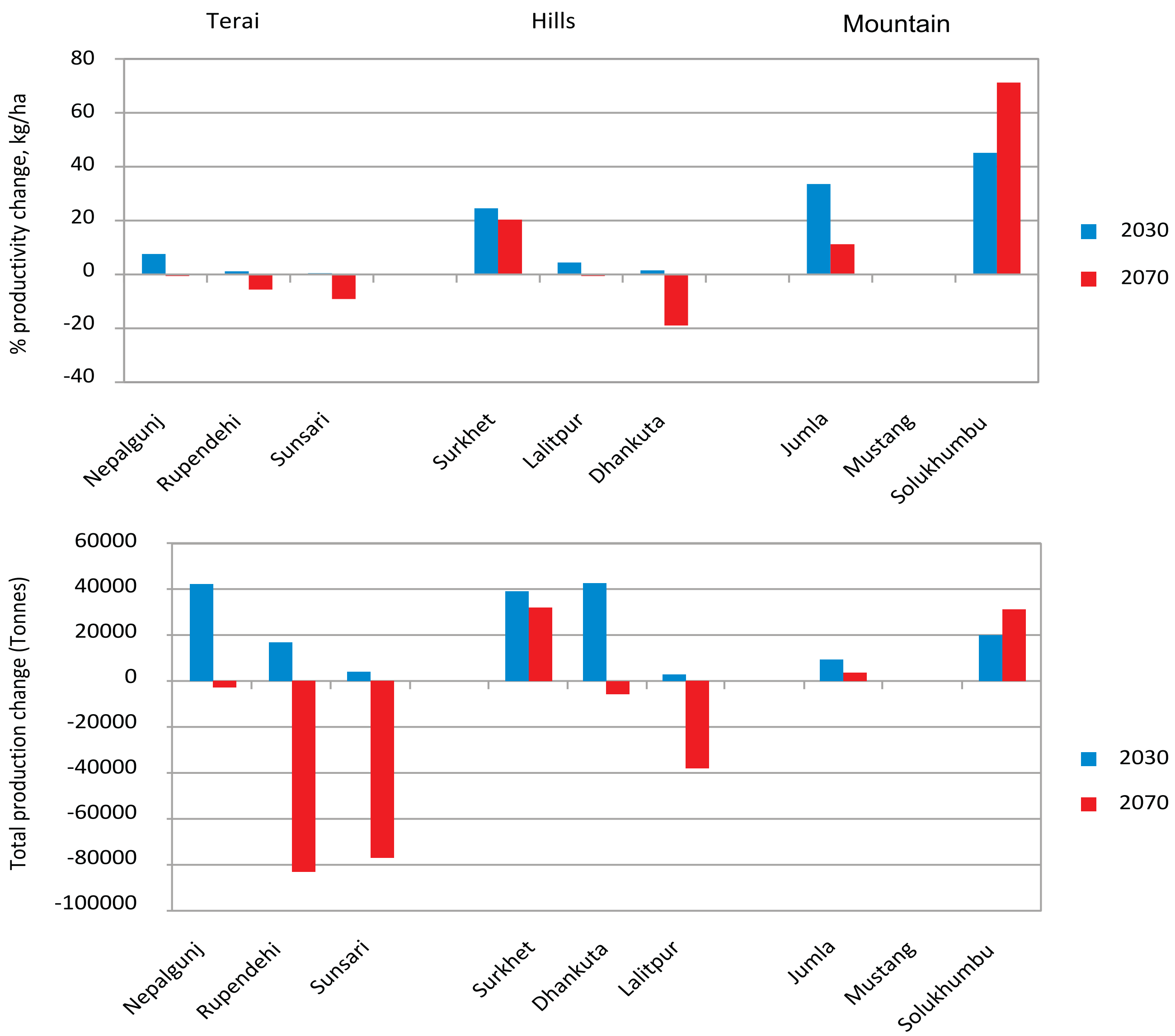


Figure 7.1. Top: Percentage Change in Rice Yield from Climate Change, relative to baseline period. Bottom: Total Change in Rice Yield from Climate Change (based on production area), relative to baseline

The analysis has looked in more detail at the runs. These show large year-to-year variations in precipitation, which will be an important factor in driving the changes. These include large decreases in yields during extreme low rainfall periods. It is important to note that in some regions, the variability in rainfall (including low rainfall periods) was found to increase significantly towards the end of the century. This indicates that one of the largest impacts from climate change could be in the form of increased variability (rather than in terms of gradual changes). A particularly strong example of this increased variability was found for the Eastern Terai. While some care must be taken in interpreting the results of one climate model, the potential for increased variability could be very important for future production and broader food security.

Maize is the second most important crop in Nepal, with a cultivated area of 870 thousand hectares, and a total production of just over 2 million tonnes (MOAD, 2012). It is particularly important in the hills, where it represents 78% of the total cultivated area. Average national productivity is, however, low at 2.5 metric ton per hectare.

The general trend for the impacts of climate change on maize is more differentiated than for rice.

- In the Terai region, there is an initial increasing production trend (in the 2030s) for the west and central areas (but not the east), followed by a sharply decreasing trend (20%) in the west in the long-term (2070s) (noting this is already a dry region).
- In the hills, there are increasing yields projected in the short-term (2030s), as well as in the long-term (2070s) in the east and central regions, but a small decline in the west in the long-term.
- In the mountains, in the short-term (2030s) there is a strongly increasing trend across all areas (though especially in the east). In the long-term (2070s) there are reductions in yield in western and central areas.

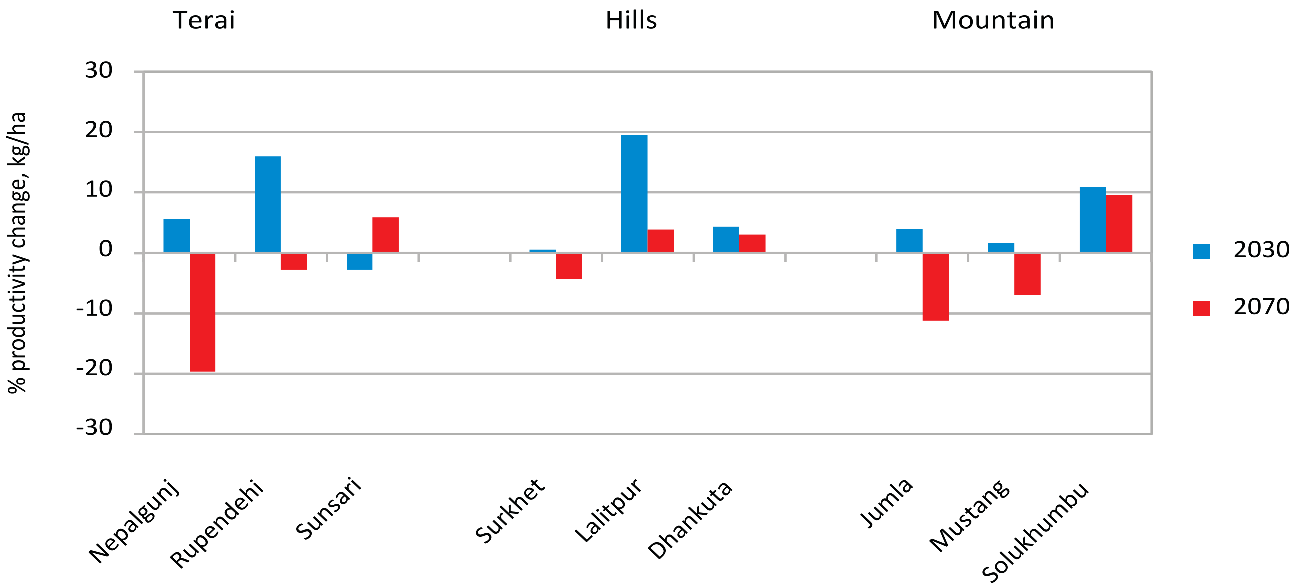


Figure 7.3. Percentage Change in Maize Yield from Climate Change, relative to baseline period

Wheat is the third most important cereal crop in the country, grown over some 765 thousand hectares, and with annual production of around 1.8 million tonnes. Wheat is cultivated in 25 percent of the total cultivated land area and contributes 19 percent to the total national cereal production. The wheat yield in the base year (2010) is 2.41 tonnes/ha. The analysis of the impacts of climate change finds:

- While an initial increase in production is projected (2030s), there are potentially large decreases in wheat production in the central and western areas of the Terai in the long-term (2070s). For the central and western region, the decreases are driven by higher temperatures.
- For the hills, there is a more mixed impact in the 2030s, but with decreases in yields are found across all areas in the 2070s. There is a particularly high decline in the western hills (though some care should be taken in interpreting this finding, as the reason for the fall needs to be further explored).
- In the mountains, there is potentially large benefit in the west (and to a lesser extent the central areas), with only modest changes in eastern areas.

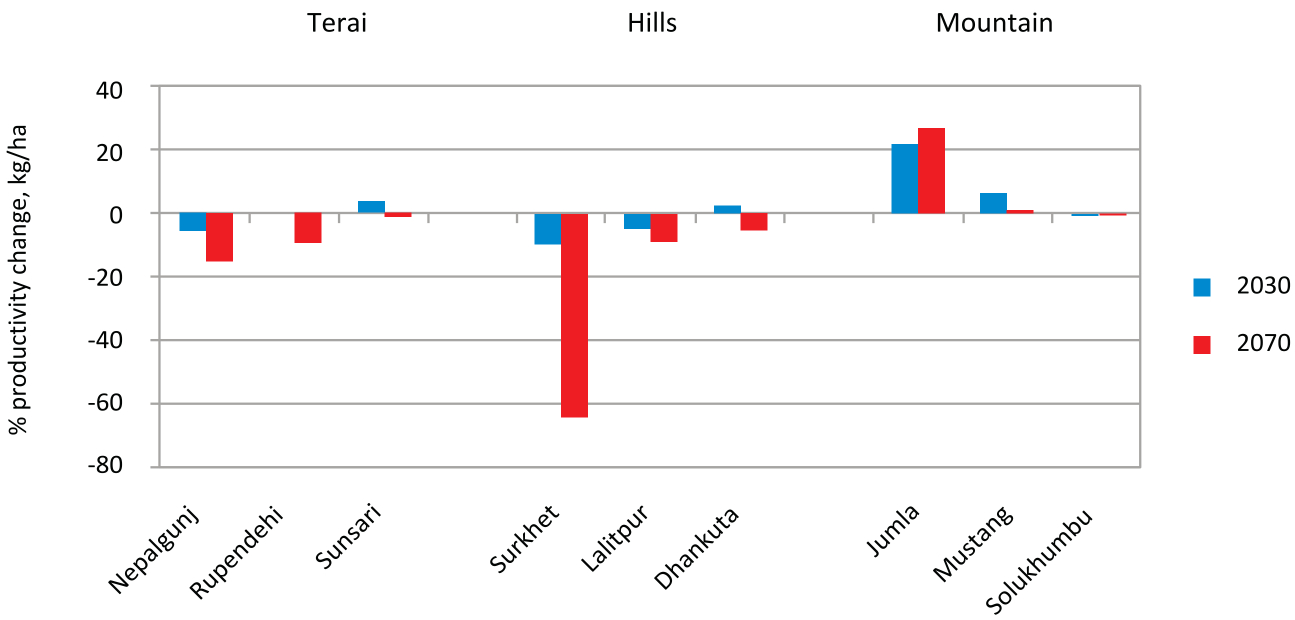


Figure 7.4. Percentage Change in Wheat Yields from Climate Change, relative to baseline period

Overall, the results show a strongly differentiated pattern over time and across the agro-ecological/development regions of the country. There are potentially high negative impacts from climate change in the Terai (especially for rice and wheat production). In some cases yields are projected to decrease by 10%-20% in the latter time period (the 2070s), which are important given the higher production (as a % of national total) of this region. There is a more varied pattern in the Hills and Mountains (including some potentially high benefits, but also negative impacts).

The negative impact on food production increases the potential risk of food insecurity for vulnerable groups, with potential impacts of malnourishment and malnutrition, and even migration (as a coping mechanism). Migration is one way that farmer supplement income in times of low farm income due to extreme events like low rainfall and drought (Lamboru Y. 2010): This has a differentiated impact by gender, as in cases of severe drought and floods, it is predominantly men that migrate while women are more likely to undertake waged labour and take out loans

It is stressed that these values do not take account of irrigation and farm-level autonomous adaptation (e.g. varietal or crop switching) but they do show that potentially climate change could be very important to the agricultural production of Nepal. Smallholder farmers are likely to be disproportionately affected by these changes, because of their more limited coping capacity.

However, additional impacts could be driven by increased rainfall variability, in addition to average temperature and rainfall trends, at least in some regions.

Valuation

While the values above show the physical changes in productivity, it is also important to look at the changes in total productivity and to consider the economic costs of these changes. To provide an indication of the economic costs, the yield changes above (on a unit hectare basis) were multiplied by the area of cultivation for each crop, and then multiplied by the prices for each crop using world market prices to estimate the total value of the agricultural yield changes (as reported in Chapter 3). This allows an analysis of the overall change in total production and value between current and the two future time periods. It is stressed that current values were applied to the two future periods to allow direct comparison between current and future impacts (i.e. values in future years are not adjusted or discounted).

The results are shown in Figure 7.5.

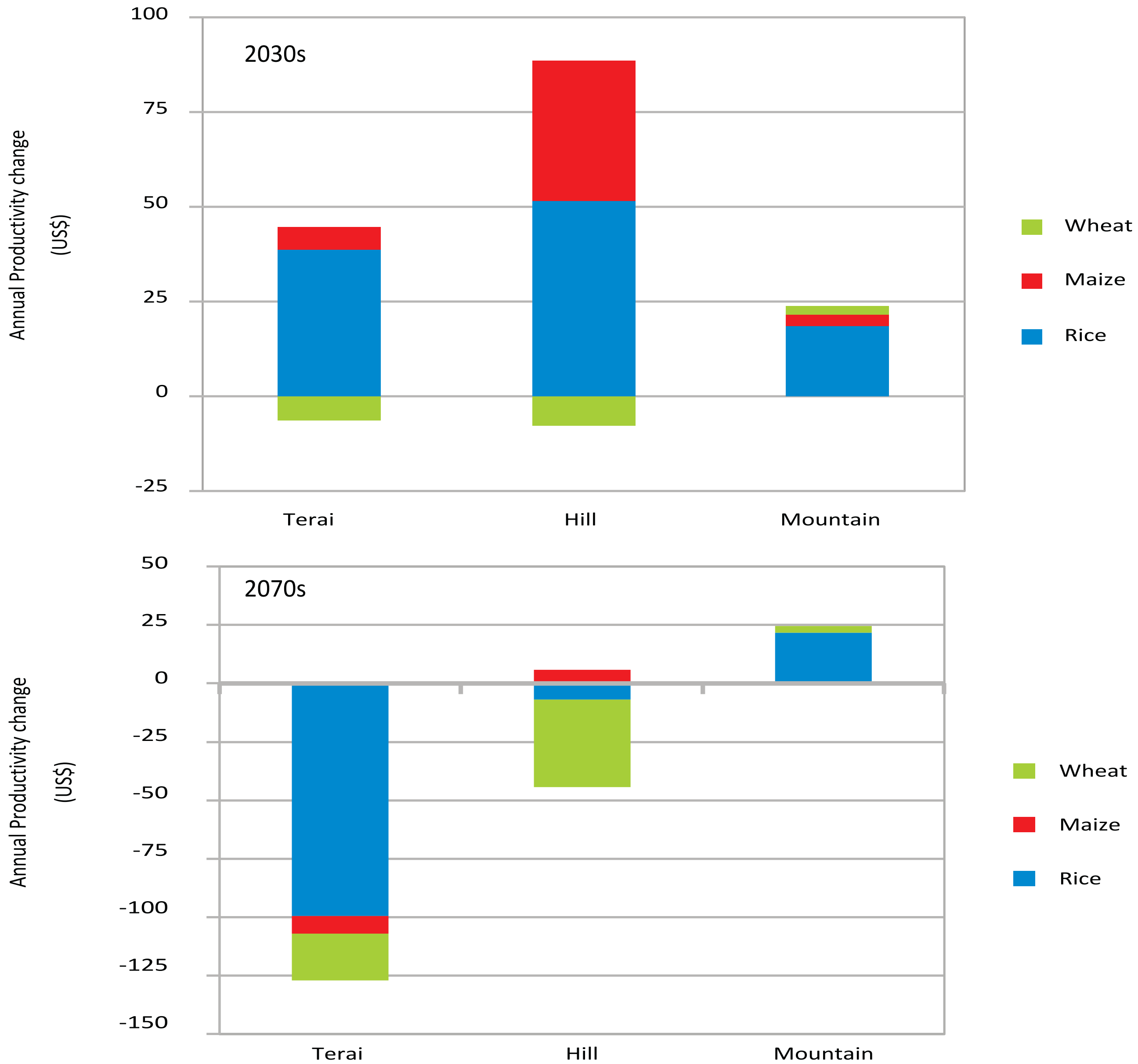


Figure 7.5. Total net costs from changes in agricultural production from climate change for the 2030s and 2070s (current prices, undiscounted)

The overall finding is that in the 2030s there will be a net increase in production and values. However, by the 2070s there will be negative impacts in terms of agricultural productivity, which could total US$140 million/year (current prices). This is equivalent to around 0.8% of current total annual GDP. It is noted that this is an annual average, and the high variability discussed above will lead to much higher impacts in some years. Note that the aggregate change hides significant variations in change between crops and areas. The reductions in 2070s are largely driven by reductions in the Terai.

The analysis assumes that current crop prices do not change in future time periods, i.e. we assume 2010 prices in the 2030s and 2070s. Whilst there are no official price projections for these future periods, sensitivity analysis has been used with world cereal price profiles with climate change as compiled by Easterling et al., (2007). Whilst the low-end prices show no change from current levels, (consistent with our core analysis assumption), the high-end prices show a 10-30% increase from current prices. These increases would be reflected in equivalent increases in yield values in these time periods.

It is noted that future world prices for agriculture (over the time periods here) are highly uncertain, and will change with future demand and socio-economic development. These future prices and trade flows will also change due to the impacts of climate change on agricultural productivity in individual countries and at the aggregate global level. These future changes have not been taken into account, and would require a global economic agricultural modelling system to assess. In the short-term, the effects of climate change on global agricultural prices are uncertain. Easterling et al. (2007) reviewed the effects of climate change on world cereal prices and found studies that indicate decreases as well as increases (relative to baseline) for modest temperature changes (e.g. 2°C global average warming above pre-industrial), though most studies indicate negative impacts at higher temperatures.

Comparison with previous results

Previous studies in Nepal (GoN, 2004; Sherchand et al., 2007; Rai et al.) have looked at the future impacts of climate change in Nepal. These studies report mixed results for Nepal, finding an increase in crop productivity at modest levels of temperature change or in certain regions (especially when CO_2 fertilization effects are factored in) but negative impacts at higher levels of temperature rise. As an example, early DSSAT modelling in the National Communication (GoN, 2004) reports that temperature rise might increase wheat output in the western region of Nepal but could lead to a decline in other regions. Rice yields were also generally anticipated to increase up to a certain temperature level. However, potential decreases in yield were reported for maize (a temperature sensitive crop) particularly in the Terai.

The DHM/APN (Sherchand et al., 2007) study applied DSSAT and reported different impacts across crop types and three physiographic regions (Terai, Hill and Mountain) with climate change. For rice, there were broad increases in yields projected across the temperature and rainfall changes, though with a lower relative increase with higher temperature changes in the Terai. For wheat, yield changes were more varied, with some reductions in yield in the Terai, but favourable changes reported in the mountains. For maize, projected yields declined in the Terai and Hill regions with higher temperatures, though there were positive effects in the Mountains. The study also highlighted that many of the crops are particularly vulnerable to variability and droughts in key stages of development (particularly pre-monsoon). Overall, the projections showed that Nepal could move from a nation of marginal surplus under a baseline normal scenario to a case where supply and demand only just balanced under the climatic change scenario (assuming no adaptation). Rai et al., also using the DSSAT model, looked at rice production in Nepal and reported that modest temperature increases (minimum temperature) had positive effects, but above 2°C, negative impacts start to arise.

Arecent application of DSSAT was also undertaken for Nepal as part of the PPCR scoping phase on agriculture (PWC, 2012), which also used other crop models and considered a wider range of crops. This study also reports high crop yield reductions in the Terai for all three main crops, even in the 2030s, with a stronger impact on maize was reported than found in the analysis here.

Discussion of uncertainty and the effects on the sector results

The analysis above is based on one future emission scenario and one downscaled climate model. As presented in Chapter 5, there is a wide range of future emission scenarios, which includes low and high emission scenarios, as well as a wide range of projected changes in temperature and precipitation (across areas and seasons) from different global and regional climate model combinations. This uncertainty needs to be factored into the interpretation of the results above.

As a result, the range of projections from drier or wetter models (and hotter and colder models) would be expected to widen the range of plausible results. As an example, warmer and drier outcomes might be expected to increase the negative impacts of climate change in the Terai, while more moderate future changes would be likely to lead to more modest or even beneficial results. As well as the future changes in average trends, an important factor concerns the changes in variability from climate change (and especially extreme variability).

Another key uncertainty relates to the effects of CO_2 on plant fertilisation (a beneficial effect of climate change, which increases productivity). The study also undertook a number of runs with CO_2 fertilisation included and excluded, at 550 ppm and 700 ppm CO_2 concentrations. For maize and rice, CO_2 interactions with the climate change scenarios led to changes in the yields within a range of +/- 10%. This is an additional uncertainty although it is within the wide variations from season to season and across the country. For irrigated wheat, CO_2 had a clear positive benefit, and at 700 ppm CO_2, yields go up by nearly 30%.

It is stressed that a key focus for future research should be to consider the outputs from a wide range of climate scenarios and models, and also agricultural models, including farm level autonomous adaptation. This uncertainty is needed to design iterative adaptation planning. It is also highlighted that there are strong cross-sectoral linkages, particularly with the water sector, which need to be factored into account in developing a holistic adaptation response.

Limitations and future research

The analysis above has considered an application of DSSAT to the agricultural sector of Nepal. The study focuses on the three main crops, but a broader analysis of all major crops would be useful. Time series data (from a secondary source) from 1990 to 2000 for the selected districts was used and there might be variations in agro-climatic conditions, management regime and productive capacity of soil and other relevant factors within the district, which have not been captured in the analysis. It is stressed that the results do not include existing irrigation – which is high in the Terai – and the results above are therefore likely to over-estimate the impacts of rainfall reductions (where these are the driving factor). It is also highlighted that a farm level response to rising temperatures will be to increase irrigation, which may mean that while crop impacts are lower, there is additional demand for water (noting the cross-sectoral issues with broader water management and hydro-electricity). The analysis also does not include farm level adaptation, which would be expected to autonomously adjust and offset some of the impacts above through changing varieties and crops (as well as irrigation). It also does not include underlying socio-economic development, and the technological and efficiency improvements likely in the agricultural sector (in line with the strong focus on agricultural development highlighted in the policy review chapter), which should increase underlying productivity in the sector. However, a number of potential impacts of climate change are omitted (see below).

Other risks to the sector

In addition to the changes from temperature and precipitation, a number of additional effects are likely to occur in Nepal, though the extent of these will vary.

In terms of agricultural production, the higher projected increases in floods (see later section) are likely to increase the flood related losses in the sector. Given the possible increases in high flows and the reductions in return periods for major events, these could be very significant, especially in the Terai which is already the most flood prone area, and also the site of the most productive agriculture. The increase in extreme heavy precipitation events, as well as possible higher numbers of rain days (see chapter 5) is also likely to increase soil erosion, which will have long-term impacts on productivity.

It is likely that the changes that are projected, especially for high emission scenarios and warming models, will lead to major shifts in agro-ecological zones. This has the potential for some benefits, as new areas are opened up and seasonal lengths increase. However, the changes in climatic zones will also affect the range and prevalence/incidence of pests and diseases. While there are uncertainties, it seems more likely that climate change will increase the range of these pests and diseases into the hills and mountains, where current cold conditions limit their spread.

Climate change will also have potential impacts on livestock (including dairy farming). There is relatively less information available on the potential effects of climate change on livestock. The studies and reviews available (Pokhrel and Pandey, 2011 Sherpa, et al. 2009; Pant, 2011) indicate a combination of possible effects, either from direct impacts (heat stress) or from indirect effects associated with diseases, impacts on pasture or forage production, climate variability and water availability or hazards/risks, and highlight potential increases in production costs and/or declining productivity. The studies identify that yaks might be particularly vulnerable to climate change, due to the fact they are acclimatised to colder temperature, and are sensitive to high temperatures, with effects potentially exacerbated by herding practices.

All of these changes need to be examined in the context of agricultural value chains. A recent scoping study on climate resilient agriculture and food security (PPCR, 2012) - is starting to look at climate change and agri-value chains. Finally, the impacts of climate change affects regional and global agriculture, and these changes will affect the agricultural sector, prices, etc. in Nepal. Further work needs to look at these changes, especially in the regional context.

7.3. The Future Impacts on the Water Sector

The starting point for the analysis of the impacts of climate change in the water sector – for both hydro-electricity plants and water-induced disasters – is to take outputs from the climate projections and run these in hydrological models. A number of previous studies have assessed potential changes in the water sector in Nepal. These include the application of watershed simulation models as well as rainfall-runoff inundation models, and (limited) application of water management models.

These studies find that climate change has potentially large impacts on precipitation, evapo-transpiration, run-off and river flows, and additionally for Nepal, there are other factors such as the changes in snow fall and snow melt, glacier melt and river flows. A key finding of previous work is that it is highly challenging for the climate and hydrological models to capture the complexity of the Nepalese monsoon, and future changes in the regional meteorology at a high spatial resolution for the country, especially given the extreme variations in topography and elevation. Some earlier studies (e.g. GoN, 2004) report potential increases in river discharge associated with increased monsoon rainfall, also noting that the increase in extreme precipitation would be a factor in increasing water-induced disasters. Other studies report that reduced flows, notably in the dry seasons, could affect hydro-electricity production (Sharma and Shakya, 2006). The analysis of future impacts on hydro-electricity and water-induced disasters are summarised below.

7.4. The Future Impacts of Climate Change on Hydro-electricity

Changes in precipitation, run-off and river flows from climate change have the potential to impact on hydro-electricity plants. In theory, higher precipitation will make more water available for hydro-electric generation, but higher temperatures will lead to higher evapo-transpiration. These changes also need to be seen in the context of existing river flow regimes and seasonal changes.

The study has undertaken new impact assessment modelling to assess the impacts of climate change on hydro-electricity. The methods and models used in the analysis were set out in Chapter 3, including the assumptions regarding future demand and capacity. The study used two sets of climate projection data, for the A1B scenario, both using the PRECIS Regional Climate Model, but with two different parent GCM: Had-CM3 (using the data from IITM as outlined earlier in chapter 5) but also an additional climate data set with the ECHAM5 driving GCM. The data was bias corrected (for precipitation) using observed and modeled hind cast data based on the Power Transformation Method (Leander and Buishand, 2007; Terink et al., 2010). This was input into the Tank and SWAT hydrological models for selected catchment areas to derive the stream flows (historical and future with climate change).

The estimation of monthly electricity generation for hydro-electric plants (both existing and candidate plants) was then estimated for the base case (using historical stream flow data) and with climate change (using projected stream flow data) using the VALORAGUA model, a Hydro-thermal Operational Planning Model. This allows analysis of plant optimisation. These results were then fed into the power system expansion WASP model, to allow analysis of electricity sector supply optimisation for the base case and 'with climate change'.

The analysis of future hydro-electricity sector investment was considered through to the year 2050, with WASP model runs undertaken for three future electricity planning periods (current to 2030, 2031-2040, 2041-2050). However, for the 'with climate' analysis, there was a need to match to the data available. The ECHAM5 projection data was only available for 2030 - 2060, and the Had-CM3 data was also considered for this period to provide consistency. Two future time periods were considered for the climate and hydrological model results: data from 2031-2040 was used for the first two electricity planning periods (current to 2030, 2031-2040, i.e. the projected flows were the same for the two planning runs), and data from 2041-2050 was used for the third electricity planning period (2041-2050).

Future Impacts on Electricity Availability Patterns

The study first assessed electricity generation patterns for the base case and with climate change, using the VALORAGUA model. Figure 7.6 shows the river flows and hydro-electricity availability pattern for a run-of-river (RoR) plant for the base case and with climate change for the two climate and hydrological projection periods (2031-2040 and 2041-2050) for the two alternative climate model projections (driven by either the Had-CM3 or ECHAM parent GCM). The analysis considers different hydrological conditions, with five hydro-conditions (very wet, wet, average, dry and very dry) with probabilities of occurrence of 0.1, 0.2, 0.4, 0.2 and 0.1, respectively. The 30 years of stream flow occurrences were used to derive these hydro conditions.

In the baseline conditions, the river flow is reduced, leading in turn to lower electricity generation during the dry season from mid-November to May (shown by the black line). This is a particular issue in dry and very dry years (shown in the top two panels of Figure 7.6), leading to reduced energy availability.

Climate change has the effect of altering these baseline flows (as shown in the coloured lines), though the effects vary with the time periods and driving GCM.

- The Had-CM3 driving GCM results (with climate change) lead to higher river flows than in the baseline in the dry and very dry periods in earlier dry season months (Nov-Jan), especially for the period 2031-2030 (noting flows drop back slightly in 2041-2050). During this period, the model projects that climate change increases hydro-energy availability due to higher river run-off for the run-of-the-river (RoR) hydro-power, reducing earlier dry season problems. However, this model also projects major decreases in the latter parts of the dry season (Apr-May) in dry and very dry years.
- In contrast, the ECHAM5 driving GCM results (with climate change) projects lower flows than in the baseline in the dry and very dry periods in early months of the dry season, implying lower hydro-energy availability, increasing dry season problems (and even shows flows above Had-CM3 in the latter part of the dry season, i.e. April-May).

An analysis has also been made of the effects of climate change on plants with storage reservoirs using the VALORAGUA model. The results are shown in Figure 7.7, again for different hydrological conditions, from very dry to very wet years. This shows very different results, as these storage plants are not affected by run of river flows (unlike run-of-river plants) thus the baseline does not vary to the same degree.

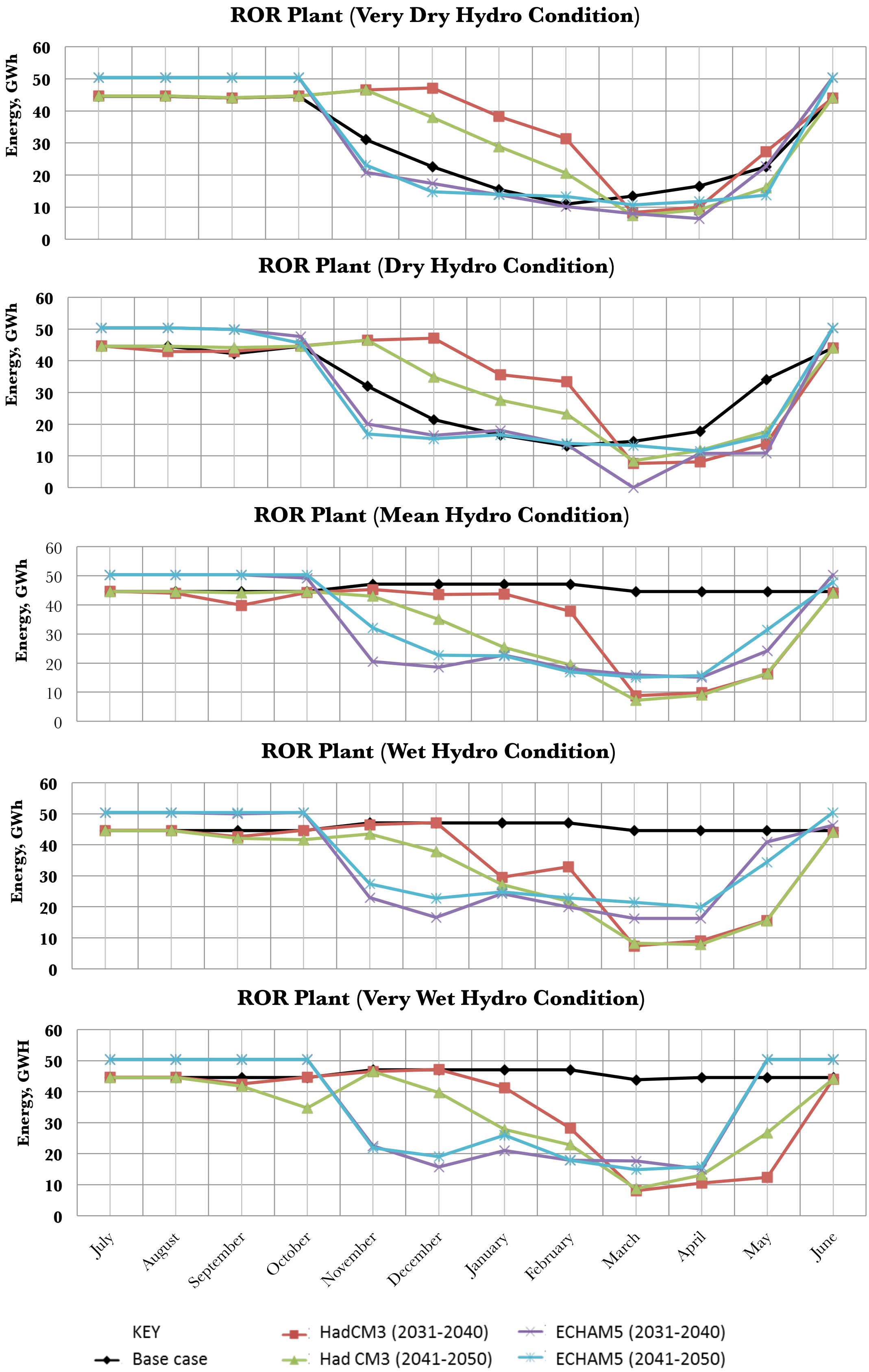


Figure 7.6. Available Energy from Run-of-River Plants for Different Hydrological Conditions for the Base Case and with climate change in periods 2013-40 and 2041-2050

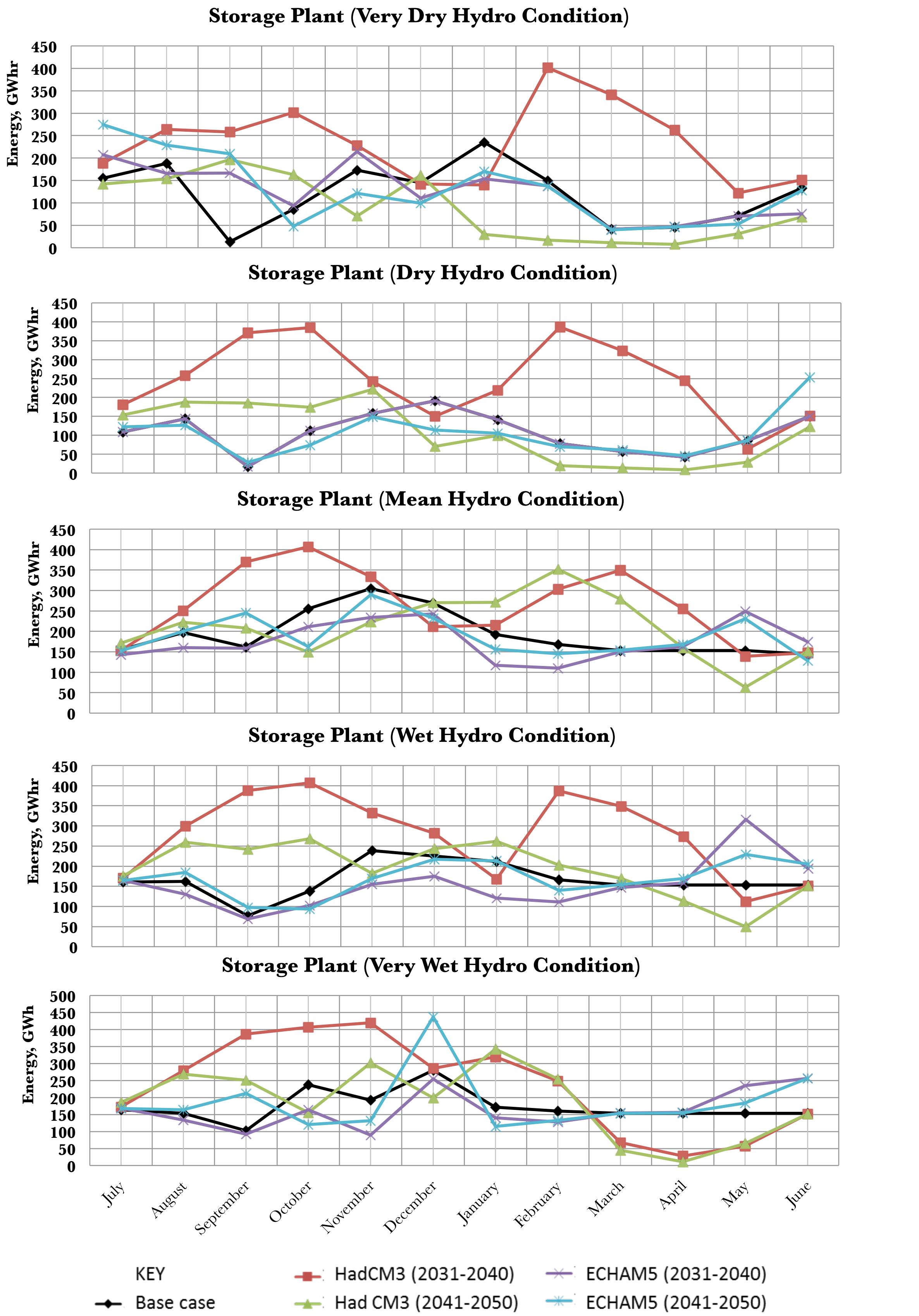


Figure 7.7. Available Energy from Reservoir Plant for Different Hydrological Condition for Base Case and with climate change in periods 2013-30 and 2041-2050

However, climate change does affect the flows and overall hydro-electricity generation (as shown in the coloured lines), though the effects vary with the time periods and driving GCM.

- The Had-CM3 driving model results are again much higher, especially for the period 2031-2040, leading to hydro-energy availability during most months compared to the baseline, but a decrease in the longer time period (2041-2050), particularly during the dry months of the year.
- The ECHAM5 model results lead to lower flows and lower availability during the first time period (2031-2040) compared to Had-CM3, but higher flows and availability during the second time period (2041-2050).

These results need to be interpreted with caution, given the high dependence on the climate model results, and the hydrological data. They do highlight that the impacts on available energy are complex, and are likely to vary over time, with the changes in variability and extreme years, but include the potential for increased or decreased energy availability.

Future Impact on the Capacity Mix

For the future system planning, the WASP model was used to estimate the combination of options to deliver the optimal (i.e. least cost) mix of power generation technologies to meet future projected electricity demand. This includes consideration of non-hydro generation (thermal or renewables) as well as imports and exports, at different planning horizons and at different electricity price levels. For the future analysis here, imports were assumed to remain at the present level and the planning was carried out to meet domestic electricity demand.

The study then estimated the future capacity mix. The WASP model was used to generate a baseline projection to 2050, estimating the optimal capacity and the mix of generation options to meet demand, based on current and candidate plants available (which includes hydropower as well as thermal plants). Under this base case, the model included a small share of thermal generation (around 4%) by 2030, as this provides a more cost-effective way to meet peak demand. The share of thermal plant increases further in later years. The analysis was then repeated with the two climate-hydrological model runs.

A higher capacity (an additional 2765 MW by 2050, of which additional hydro-power capacity of 965 MW) was needed on the system with climate change when using ECHAM5 model results, due to the reduced water flows and reduced energy availability. This led to a higher share (around 8% by 2030) of thermal generation. This would also increase the generation of GHG emissions.

For the Had-CM3 driving GCM, the capacity was closer to the base case, with a decrease in capacity in early years due to the increase in flows and thus lower capacity requirements, changing to a slight increase (of 330 MW) by 2050. The results are shown in Figure 7.8/Table 7.2.

Table 7.2. Power Generation Capacity – Additions (MW) over the three planning periods for base case and two driving GCMs

	2013-30			2031-40			2041-50		
	Base	HadCM3	ECHAM5	Base	HadCM3	ECHAM5	Base	HadCM3	ECHAM5
Capacity Mix, MW									
Hydro	4,533	4,551	6,213	7,669	7,324	11,131	22,532	22,863	23,497
Thermal	213	213	513	1,363	1,313	1,963	2,513	2,513	4,313
Import	100	100	100	100	100	100	100	100	100
Total	4,846	4,864	6,826	9,132	8,737	13,194	25,145	25,476	27,910
Share %									
Hydro	94%	94%	91%	84%	84%	84%	90%	90%	84%
Thermal	4%	4%	8%	15%	15%	15%	10%	10%	15%
Import	2%	2%	1%	1%	1%	1%	0%	0%	0%

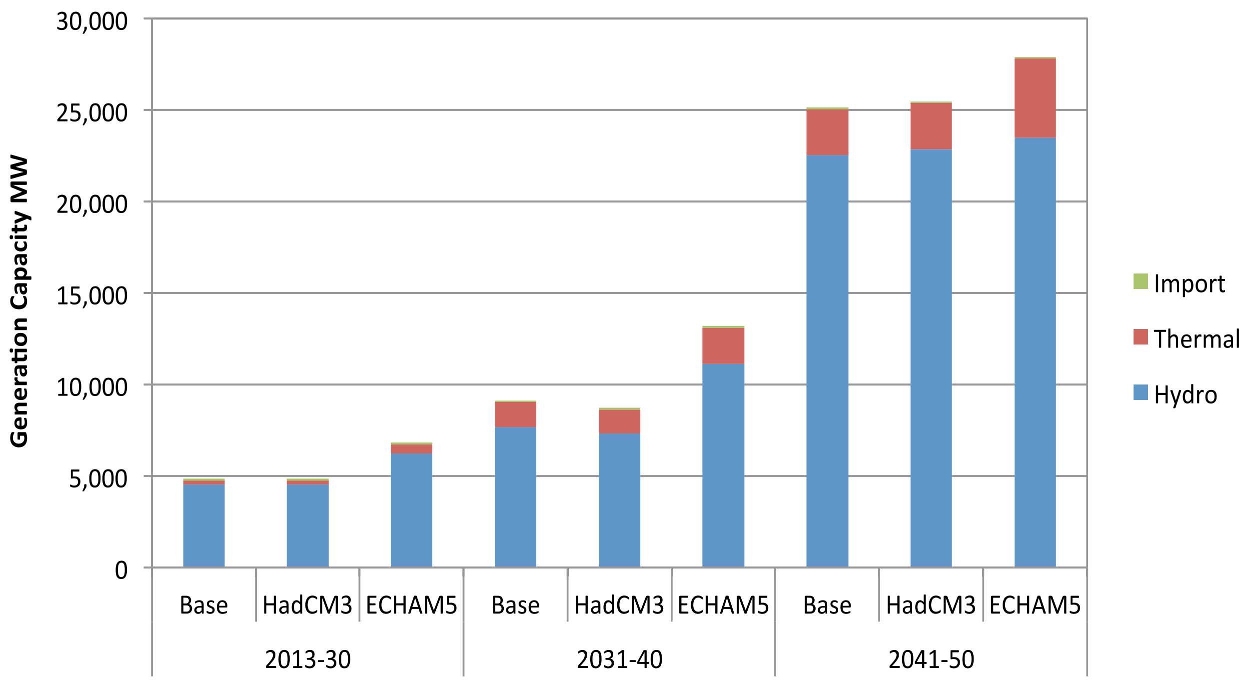


Figure 7.8. Power Generation Capacity (MW) for Base Case and with climate change (for Had-CM4 and ECHMA5 driving GGMs) in three system planning periods

Future Impact on Plant Capacity Scheduling

The power generation capacity additions projected by the model, with and without climate change (for the two different driving GCMs), were then estimated and are presented in figure 7.9. Following the results above, there are large differences found between the two driving GCMs.

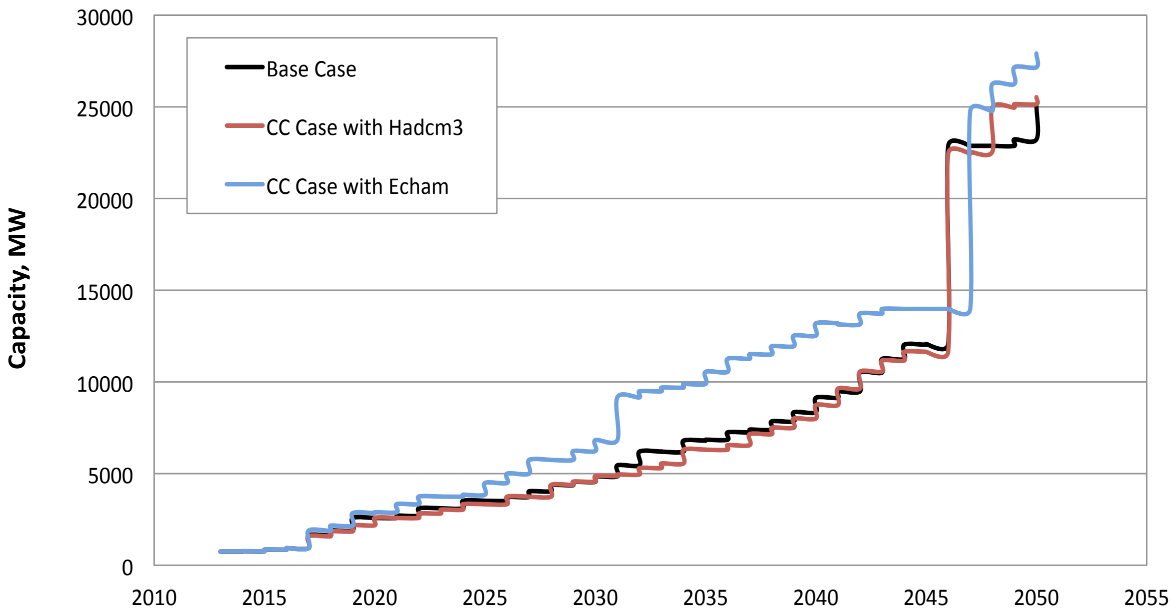


Figure 7.9. Plant Scheduling for Base Case and with climate change (for Had-CM4 and ECHMA5 driving GGMs) in three system planning periods

The analysis of future climate change with the ECHAM5 model (shown in blue) projects greater numbers of thermal plants are installed up to 2040, and installations of hydro plants are also brought forward during this period, compared to the base case (and the climate change scenario). However, these differences are reduced in the final planning period (2041-2050).

For the analysis with Had-CM3 (in red), there is little difference in the plant capacity scheduling when compared to the base case, though with climate change in the early planning periods (to 2040), there are a slightly lower number of thermal plants installed and some hydro plants are deferred, due to the higher hydro-energy availability projected with this model in the first planning period (i.e. due to higher run-of-the-river (RoR) hydro-power generation during the dry months of the dry and very dry years). It is only in the final planning period (towards 2050) when additional capacity is installed over and above the baseline (without climate change).

Future Impact on the Generation Mix

The electricity generated, with and without climate change, is presented in Figure 7.10. The system is dominated by hydro-electricity. However there is higher thermal generation and lower hydro generation under the ECHAM5 model compared to the base case due to the lower dry season flows (as compared to a slightly lower level of thermal generation under the Had-CM3 model compared to the base case).

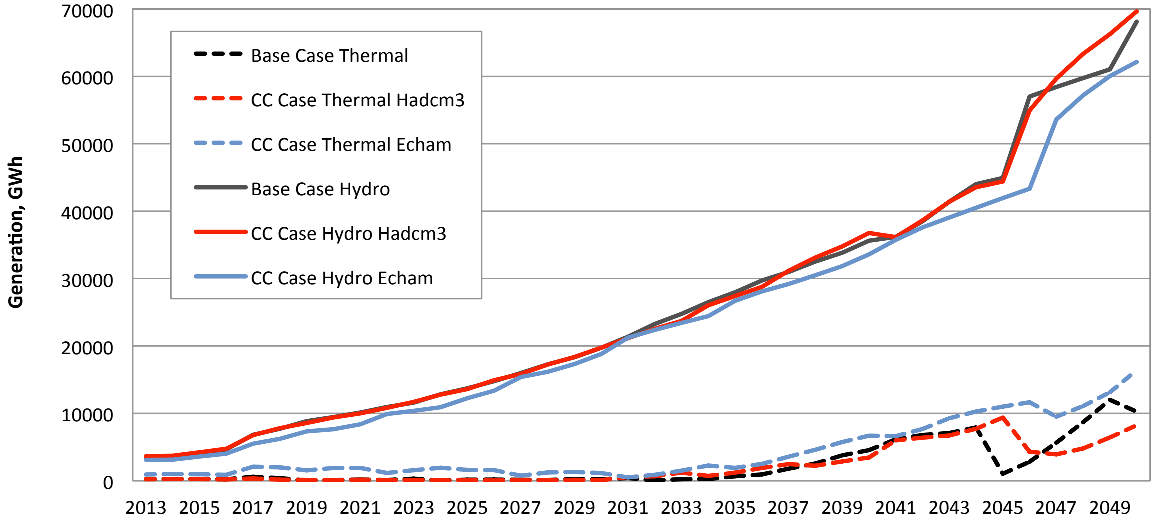


Figure 7.10. Generation for the Baseline and with climate change (for Had-CM4 and ECHMA5 driving GGMs)

Impact on the Loss of Load Probability

The WASP model has also estimated the loss of load probability (LOLP). This is a reliability index that indicates the probability that some portion of the load will not be satisfied by the available generating capacity. More specifically, it is defined as the proportion of days per year or hours per year when insufficient generating capacity is available to serve all the daily or hourly loads. NEA has specified a maximum permitted LOLP of 5.0 days per year i.e. LOLP of 1.37%. However, NEA currently has inadequate power generation capacity and the LOLP is very high, in the order of 50% or above.

The results are presented in Figure 7.11. Under the baseline, the addition of additional capacity is expected to reduce the LOLP to within the specified level from 2019 onwards. However, climate change affects these future levels, especially for the run with ECHAM5 where the LOLP rises significantly in the 2040s.

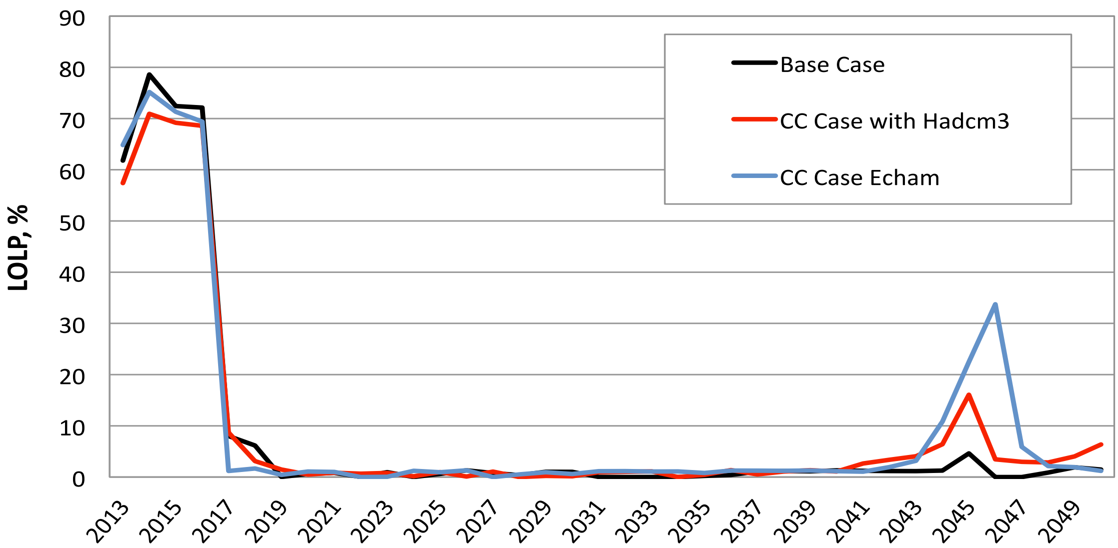


Figure 7.11. Annual Loss of Load Probability

Future Impact on Investment

The total investment costs (present worth) of the power generation system expansion to 2050 in the base case and with climate change scenario (for the two driving GCM runs) are presented in Table 7.3. The total cost includes construction (investment) costs, operation and maintenance costs, fuel cost (in the case of thermal plants) and the costs of energy not served.

The ECHAM5 model results in higher generation expansion costs across all planning periods, though notably in the first two periods. The additional generation expansion cost totals US$2,580 million above the baseline over the period to 2050 (present value of total investment over the period from current to 2050), due to the lower river flows, especially during the dry season.

In contrast, the Had-CM3 model results in lower generation expansion costs over the first two planning periods, and while there is an increase in the final period, there is a reduction of generation expansion costs of US$170 million (present value) over the period to 2050, compared to the baseline (i.e. a benefit). This benefit arises from the higher river flows in the dry and wet seasons in the short-medium term.

Table 7.3. Total Generation Expansion Cost, US$Million (present value, 2013 prices)

Planning period	Scenarios	Total Investment, Million US$ (2013 prices) p.v.	Change from baseline present value
2013-2030	Base Case	3,690	
	Had-CM3 Climate Change	3,560	-130
	ECHAM5 Climate Change	5,310	1,620
2031-40	Base Case	780	
	Had-CM3 Climate Change	600	-180
	ECHAM5 Climate Change	1,650	870
2041-50	Base Case	650	
	Had-CM3 Climate Change	800	140
	ECHAM5 Climate Change	750	95
Total	Base Case	5,120	
	Had-CM3 Climate Change	4,960	-170
	ECHAM5 Climate Change	7,710	2,580

Discussion

The analysis above assesses the potential impacts of climate change on river hydrology and hydro-electric generation, and following this on future overall system capacity. The impact of climate change is dependent on the GCM model used for hydrological projection. The use of ECHAM5 results in increased costs compared to the base case, while the use of Had-CM3 results in the opposite finding (i.e. benefits compared to the base case). This is because the Had-CM3 data (from IITM) projects an increase in river run-off during the dry months with climate change: as a result, the total cost of power generation is lower. The opposite finding arises with ECHAM5 due to the need for greater investment in storage plants and higher thermal plant on the system.

Discussion of uncertainty and the effects on the sector results

The analysis above is based on one future emission scenario and one downscaled climate model, but with two alternative driving global climate models (Had-CM3 and ECHAM5). As presented in Chapter 5, there is a wide range of future emission scenarios, which includes low and high emission scenarios, as well as a wide range of projected changes in precipitation (across areas and seasons) from different global and regional climate model combinations. An example of the latter can be seen with the changes in monthly precipitation and number of dry days duration (Figure 5.7) for different sites in the country. For most of the dry season months, there is a wide range of outputs across the different downscaled projections, though it is noted that there is a more robust change for January, which sees large, increased dry spell duration in most cases. Those models that indicate greater reductions in dry spell precipitation will therefore lead to increased damages.

There are also differences resulting from alternative hydrological models, and the detail captured by daily versus monthly models (as outlined in Chapter 3). This can be a particular issue for capturing dry season flows, which are important for run-of-river hydro (i.e. for capturing the reductions in low flow from the annual flow duration curve of daily mean flow against exceedence probability). As the VALORAGUA and WASP models use monthly data they do not fully capture the impact of daily fluctuations in hydrology - and the low flows in the exceedence curve. In cases where this leads to reduced flows, this implies future impacts of climate change may be being underestimated. Overall, the choice of climate and hydrological model can change the direction of the sign of change, and thus whether there are negative impacts (reduction in low flow or an increase in high flow) or benefits (increase in low flow, reduction in high flows). Importantly, these differences will also vary across catchments and times of the year. It is highlighted that using historic data for the design of plants will not capture these possible future changes.

This uncertainty needs to be factored into the interpretation of the results above, i.e. the range of results from the two alternative climate models (above) is only partially representative of the range of future effects. It is stressed that even the use of two driving GCMs models (for one scenario and one RCM) is not sufficient. Other studies that have compared alternative SRES scenarios (Babel et al., 2011), for the Bagmati Basin up to Karmaiya in the Terai, also found large differences between an A2 and B2 scenario, even in the near-term. They also found differences along the catchment, i.e. between the upper and lower part of the basin.

Further inter-model comparison of climate projections, and also alternative hydrological models, are needed before robust conclusions should be drawn. It is also highlighted that the Tamor River stream-flow changes above include changes in snow melt from climate change, as a combination of Snow-Runoff Model and Rainfall-Runoff Model was used in this case. However, neither analysis captures the additional effects of glacial melt water (see earlier discussion in Chapter 5). Future changes in glacial melt from climate change will affect river flows, especially for those rivers where it currently contributes a higher proportion. These effects add a further layer of uncertainty to the results above and highlight the need for enhanced monitoring and research.

Overall, the results clearly show that climate change could potentially have a major impact on future generation and investment, but the uncertainty necessitates an iterative response, with increased research, monitoring, and decision making under uncertainty for future investment decisions.

Other risks to the sector

There are additional risks to hydro-electric plants from climate change that are not captured in the analysis above.

This includes the risks to hydro-electricity generation from increased high flows (i.e. from increased heavy precipitation during the monsoon) and the risks of damage to hydro-electricity plants from floods. Heavy precipitation and increased soil erosion can result in higher sediment flows in the river, which can reduce the lifetime of storage projects. It can also damage run-of-river projects, as the desanding basins (sediment traps), provided to control the sedimentation may not be able to control sediment flow passing through, leading to increased wear and tear of the turbine blades. This results in increased down-time for more frequent maintenance.

While the costs of these impacts have not been estimated above, the analysis of the adaptation costs to respond to these changes have been captured in the adaptation analysis (and future investment profiles) in chapter 8. This addresses the additional investment costs to build greater resilience for future plants, and the other operation and maintenance costs from increased maintenance and faster replacement cycles.

There is also a potential increase in risks associated with any change in the incidence (or severity) of GLOF events, at least for some plants. The majority of planned projects are located near the headwater regions of the Himalayas and several of the projects include reservoirs. Consequently, their vulnerability to GLOFs is likely to increase significantly (Arya, 2007; Matambo and Shrestha, 2011).

It is highlighted that the expansion of hydro-electricity needs to be seen in the context of the overall water supply-demand balance. Future work needs to expand the analysis to consider overall water demand, noting the high complexity and inter-linkages between sectors. This will require detailed water management modelling and integrated water resource management (IWRM). While run-of-river plants are not consumptive (i.e. they do not use water), reservoirs do result in some loss due to evaporation (though this is likely to be low in the Nepalese context). There is also an issue of inter-sectoral linkages, and the need to balance supply and demand for municipal, industrial, agricultural irrigation and hydro-electricity. This is more of an issue for multi-functional reservoirs, though there are potentially more storage reservoirs planned for the future in Nepal. An issue may arise where downstream irrigation increases due to climate change, affecting reservoir water release schedules and may affect the optimal production conditions for generation, so for example, the need to meet irrigation requirements on the Terai could lead to suboptimal production conditions for hydro-electricity plants upstream. The issue of water management is also relevant in the context of trans-boundary river catchments between India and Nepal. These will be important in future years even without climate change, but shifts in precipitation and flow could exacerbate these issues (e.g. Downing et al., 2012).

There are also issues from climate change affecting electricity demand. The increase in temperatures would increase cooling demand (which is primarily met through electricity) in the hotter months of the year, particularly as higher air conditioning penetration rates would arise due to rising incomes and service sector demand. At the same time, warmer temperatures in the colder months of the year would reduce heating demand, though this is met from a combination of fuels as well as electricity. These issues could significantly change the annual demand and thus the capacity needed, and could even change the peak demand (e.g. from the current peak in

January towards a peak in the hotter months of the year, particularly the monsoon season) which would require additional capacity on the system. This issue warrants future analysis, and is a priority for future electricity system capacity planning. There are also linkages between the electricity sector and the agricultural sector through the use of water pumping for irrigation, noting that future climate change would be likely to increase irrigation and thus electricity consumption.

Limitations and future research

As highlighted above, the large variation between climate and hydrological models, over different time periods and different river catchments, means that future studies would benefit from using outputs from a wider range of downscale climate and hydrological models.

There is also a limitation related to the power sector investment model in the present analysis. Models like WASP consider the variability of water inflows by means of typical hydrological conditions with associated probabilities of occurrence. It does not allow annual variations in hydro energy availability during the planning period (this was the reason for splitting the study period into three sub periods in our WASP model analysis). This means averaging assumptions (in future years) for each planning period do not capture the variability in flows and energy generation. It would therefore be useful to carry out a more rigorous study using a power sector planning model that considers variability in hydrological patterns on an annual basis.

Related to this, the current modelling suite used monthly data and hence the impact of daily fluctuations in hydrology - and the low flows in the exceedence curve - cannot be adequately studied. In order to assess the impacts of climate change on hydropower development more adequately, it would be useful to carry out a more rigorous study using a power sector planning model that uses daily data. This would be particularly important in looking at the planning response to future changes, and on the balance of plant type.

7.5. The Impacts of Future Climate Change on Water-Induced Disasters

The analysis of water-induced disasters also used the hydrological modelling analysis and assessed the potential changes in the frequency and severity (intensity) of river flows and flooding events with climate change, considering the potential increase in future loss of life and damage costs.

As outlined in Chapter 5, the climate model projections show a possible increase in rainfall during the monsoon season in Nepal. This may have a number of effects, depending on the nature of this change. First, it is possible that the intensity of heavy rainfall events during the monsoon may increase in Nepal. This higher intensity (higher hourly or daily maximum rainfall) will increase run-off and high river flows and thus lead to more extreme floods due to higher high flows and flood depth. Second, the additional rainfall may occur as an altered frequency of rainfall events, i.e. the number of days (or continuous number of days) on which rainfall or heavy rainfall occurs, which has the potential for increasing the frequency of floods. Of course, both of these effects may arise together. These changes are also important in relation to land-slides and land-slips.

To assess the potential effects, the analysis of the two detailed river catchment hydrological modelling outputs was used, with a focus on the high flows associated with flood events. Given the probabilistic nature of extreme high flows, this also requires additional analysis, to consider the change in return periods, e.g. of 1-in-10 or 1-in-100 year events.

The analysis initially ran the Tank model with bias correction, as reported in Chapter 3. However, as this did not capture high flows adequately, the results from on going research/work in specific river basins was used and further assessed. The analysis considered the annual maximum daily flows for different climate projections, using the SWAT model results for Tamor River at Mulghat and NAM model results for Bagmati River at Sundarijal, using a Gumbel Frequency Distribution.

As climate change increases high river flows, this leads to two inter-related outcomes. First, there may be an increase in the intensity of high flows associated with more extreme heavy precipitation events or continuous rainfall, potentially leading to more damaging floods from faster flows, higher flood depths and a larger area flooded. Second, there may be a change in the frequency of high flow events leading to floods occurring more frequently. Both these changes will alter the loss-frequency curve of river flood damages, i.e. the probability of flood events of a defined size/loss level, which is used to estimate the expected annual damage. This is illustrated in Figure 7.12 below, which shows the baseline loss-frequency curve (where the columns represent events of a defined size and their associated frequency) and the potential change in the curve with climate change[8].

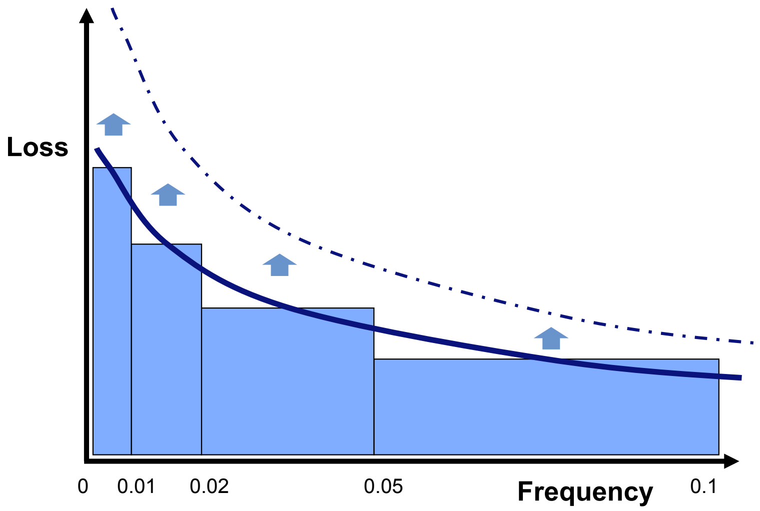


Figure 7.12. Possible change in the loss-frequency curve (loss in $ against annual probability) and average annual expected damage (sum of columns) before (solid line) and after climate change (dotted line)

The hydrological model results were analysed to look at two inter-related questions. First, to look at the change in the frequency of current return periods, i.e. for a high flow event that happens 1 in every 10 years now (as a historical average), what will be the future return period for that same flow with climate change, i.e. how much more frequently will such an event occur ? Second, how much will the magnitude of a given high flow increase by, i.e. how much bigger is the 1-in-10 year flow event under climate change and by how much might this increase damages ?

[8] note these curves are sometimes presented with frequency [probability] on the y-axis and losses on the x axis and also that the exact shape of the change will vary with the changes on river flow/distribution

The analysis first examined the differences in the changes for the Tamor River at Mulghat using the SWAT model results. This compares the results for the A1B Scenario using the PRECIS RCM data from two different parent GCMs - Had-CM3 and EHCAM03 from DHM. Note this still only represents a limited sampling of the climate models and scenarios. Figure 7.13 shows the annual flow duration curve (daily mean flow against exceedence probability) for this river, comparing historical data against these two future projected runs with climate change for the period 2030 to 2060. This indicates increases in high flows (on the left hand side of the figure) for the ECHAM driving GCM, which infers an increase in daily mean flows and flood risk/damage. However, the increases from the alternative driving GCM (Had-CM3) indicate only small changes in high flows.

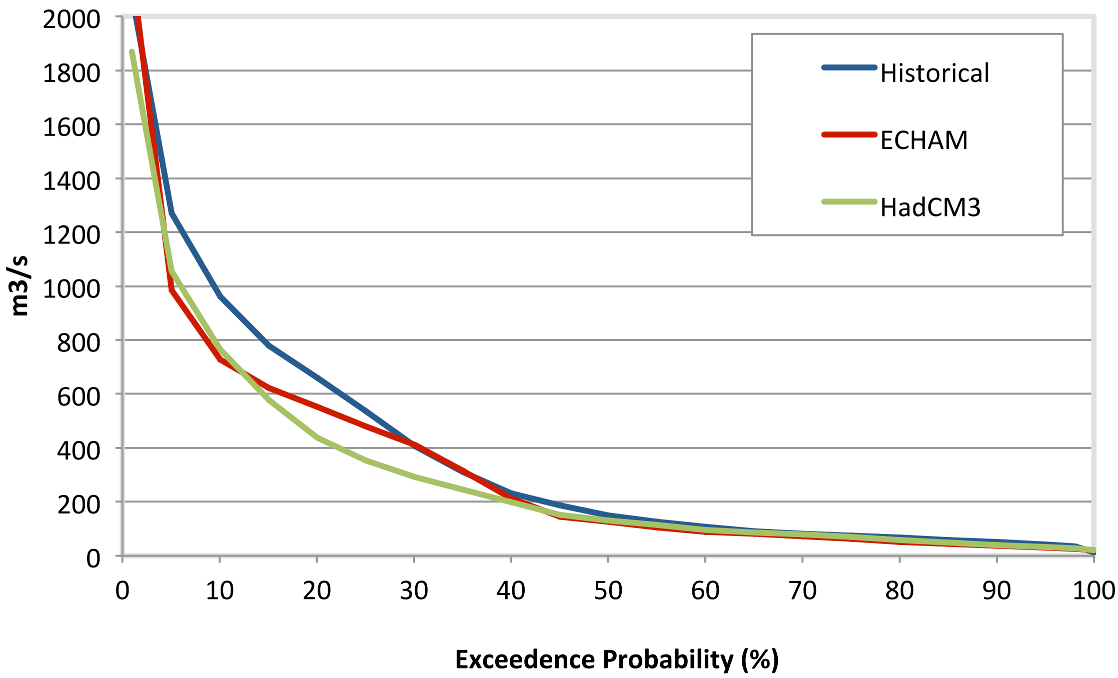


Figure 7.13. Annual Flow Duration Curve of Tamor River at Mulghat. Historical versus future (2030 – 2060)

Source of data: NDRI.

The model results were analysed to derive return periods. Flood frequency analysis is normally carried out using instantaneous maximum annual flood values but these were not modelled as the time steps of both SWAT and NAM models were daily. Hence, a ratio of flood estimates using instantaneous annual maximum flood values and the annual daily maximum flood values were used to estimate the instantaneous flood estimates.

The results for the Tamor River at Mulghat are shown in Table 7.4/Figure 7.14. The results indicate that climate change will lead to more intense high flows for current return periods (i.e. with events of a certain probability of occurring). To illustrate, an event that occurs once every 10 years (on average) now will be associated with higher high flows in the future than it does today, because of the increase in precipitation with climate change. The effect is more pronounced with the driving ECHAM GCM model. As an example, while a 1-in-10 year flood event (with a 10% annual probability) has historically been associated with a flow of 5,124 m^3/second, this will increase with climate change by 50% (to 7,720m^3/s) for the ECHAM model and 30% (6,586 m^3/s) for Had-CM3 by mid-century due to the additional precipitation and river flows with climate change. An analysis across the flow levels of different return periods (the columns in the figure) shows a similar relative increase across all return periods for both models. At the same time, the likelihood of a flow associated with a current 1-in-10 year event is likely to become more common. This can be derived from reading across the table. An event that was previously associated with a 1-in-10 year event (5124 m^3/s) is now likely to happen every 2 to 5 years with climate change. Perhaps of the greatest concern, the risks of very exceptional and highly damaging events is projected to increase, so that a 1 in 100 year event (as currently experienced by historical data) is projected to occur every 10-20 years (ECHAM) and every 20-30 years (Had-CM3) due to climate change.

Table 7.4. Projected Effects of Climate Change for the Tamor River at Mulghat

Return Period (Years)	Historical (1965 - 2006)	Echam (1930-2060)		HadCM5 (2035-2059)	
	m3/s	m3/s	% Change	m3/s	% Change
2	2,973	4,407	48%	3,698	24%
5	4,267	6,400	50%	5,434	27%
10	5,124	7,720	51%	6,586	29%
20	5,946	8,987	51%	7,691	29%
50	7,009	10,627	52%	9,122	30%
100	7,807	11,856	52%	10,195	31%
500	9,649	14,697	52%	12,675	31%
1,000	10,441	15,919	52%	13,742	32%

Note: % Change is the percentage change (increase in flood values from the historical flood estimates) for projected climate change scenario.

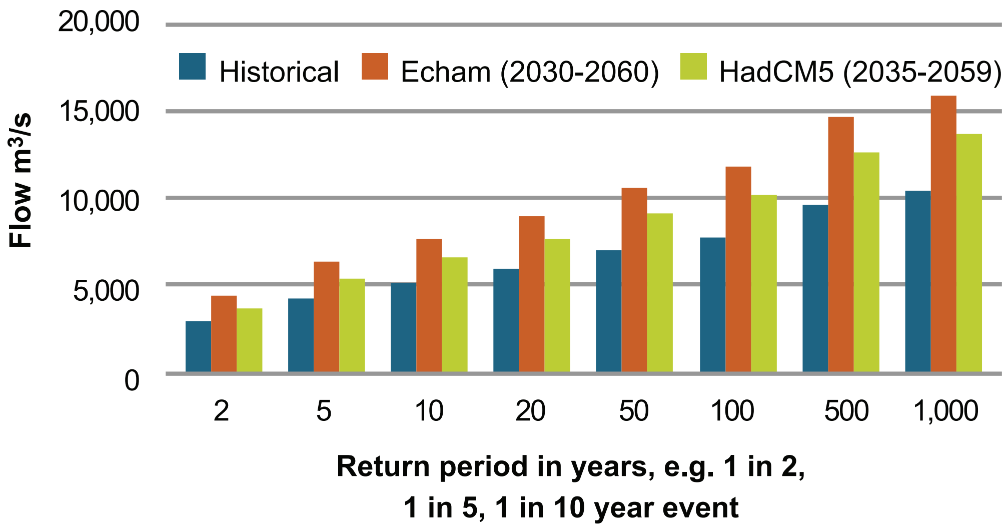


Figure 7.14. Change in discharge for certain return periods – historical levels and for two alternative climate model simulations for the future (mid century) – for the Tamor River at Mulghat

Source of data: NDRI.

The results show increases in both the severity and frequency of high flow events, and thus increases in the frequency of floods, but also imply increases in the damage caused by floods, because of higher high flows (as risks and flood damages rise sharply with water flow intensity and flood inundation depth.)

A similar analysis has been undertaken for the Bagmati River at Sundarijal-shown in Figure 7.15. This uses results from the NAM model for projected climate data (A1B Scenario, PRECIS RCM data from two parent GCMs-Had-CM3 from IITM and EHCAM03 from DHM for the period 2020-2060). The results are presented showing absolute and percentage changes. An additional comparison is presented with the monthly Tank model, to show the differences between the monthly and daily data.

In this case a clear increase in high flows is seen for both driving GCM models, as seen on the left hand side of the figures. This highlights that the impacts of climate change differ between river basins, i.e. they are very site specific. It also highlights the large differences that can arise from the choice of climate model and the hydrological model. There are significant differences in the future projected flow duration curve for climate change between the two driving GCM, but there is also a large difference between the use of the same climate model output in the monthly Tank model and the daily NAM model – in this case, even the sign of the change differs – with the monthly hydrological model projecting a decrease in high flows while the daily model projecting an increase.

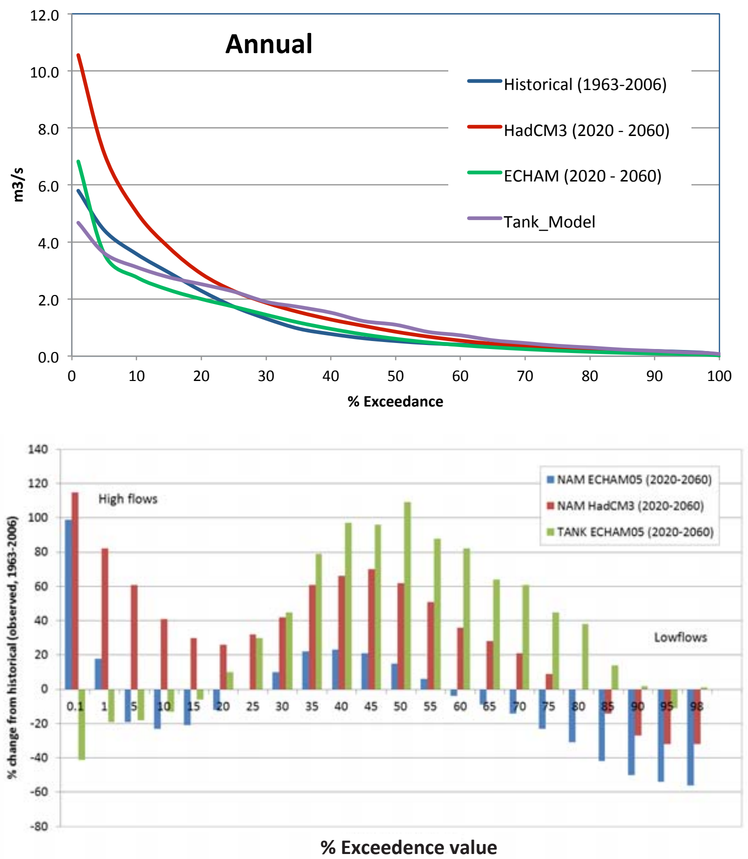


Figure 7.15. Annual Flow Duration Curve of Bagmati River at Sundarijal.
Top: Historical (1963-2006) versus future (2020 – 2060).
Bottom: % change in flow percentiles compared to historical

Source of data: NDRI.

Further analysis indicates an increase in high flows (intensity) and decrease in return period of defined events (increase in return period frequency), though in this case the results between the two models are closer.

In the period 2020-2060, there is a projected 78%-100% increase in the intensity associated with given return periods, i.e. the intensity of a 1-in-10 year event (historically 34m^3/s) will approximately double (e.g. on average there will be an event with flows of 65-67m^3/s every 10 years). Linked to this, the return period of specific flow thresholds will become more frequent, e.g. the change of a flow intensity previously associated with a 1-in-10 year event will happen once every 2-5 years. Again, there is a particularly dramatic increase in the flow associated with a 1-in-100 year event (i.e. 62m^3/s, which occurs currently only once every 100 years on average could become a 1-in-10 year event by mid-century based on these projections).

Table 7.5. Projected Effects of Climate Change for the Bagmati River at Sundarijal

Return Period (Years)	Historical (1963 - 2006)	Echam (2020-2060)		HadCM5 (2020-2060)		HadCM5 (2010-2039)	
	m3/s	m3/s	% Change	m3/s	% Change	m3/s	% Change
2	12	21	78%	22	92%	27	132%
5	25	47	87%	49	96%	76	202%
10	34	65	90%	67	97%	111	227%
20	43	82	92%	84	98%	146	243%
50	54	104	94%	107	99%	192	257%
100	62	121	95%	124	99%	227	265%
500	81	160	96%	162	100%	308	279%
1,000	90	176	97%	179	100%	343	283%

Note: % Change is the percentage change (increase in flood values from the historical flood estimates) for projected climate change scenario.

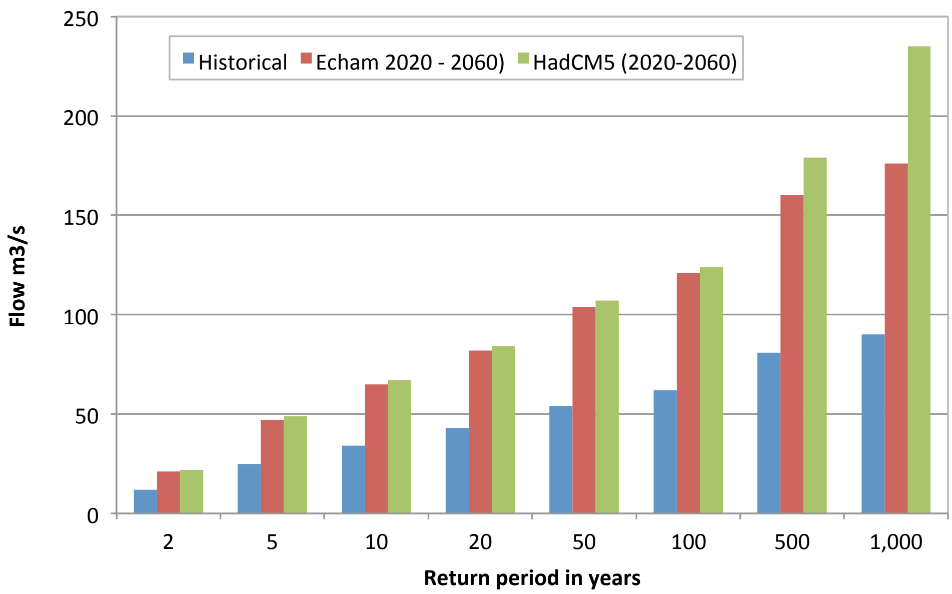


Figure 7.16. Change in discharge for certain return periods with climate change - Bagmati River at Sundarijal

Source of data: NDRI.

A third set of data exists from a collaborative study on flood risk assessment in the Lower West Rapti Basin (LWRB), carried out jointly by International Centre for Water Hazard and Risk Management (ICHARM), Public Work Research Institute (PWRI), Japan and Nepal Development Research Institute (NDRI), Kathmandu, Nepal in 2011-2012. This uses two alternative GCMs, and investigates flood frequency using a threshold level in the West Rapti River of 1500 m^3/s, which was defined as 'Low Danger Water Level' of 5m in the discharge gauging station at Kusum, and corresponds to a flood threshold. To analyse the damage caused by the flood, flood hazard mapping of West Rapti River was undertaken using a Rainfall Runoff Inundation (RRI) model, investigating the flood of 2007 for comparison. This allowed the derivation of the relationship for household physical damage and the agricultural damage with flood depth and duration. An example of the direct damage curve is shown below. The analysis then assessed the change in 25 and 50 year return periods, with and without climate change. Again this shows high differences between the driving GCM: while one of the models showed increased discharge levels with climate change, such that probable discharges would be almost twice as high as current, the other showed little difference. The damage curves were then used to assess the future changes in flood frequency and depth with climate change. This indicated a very large increase in future flood damages, with increases potentially of more than 50% and even as high as 200% in the far future. For agriculture, the area under inundation was also projected to increase, rising by 60% - 80%.

Overall, the variation in results across scenario, climate models, hydrological models, time periods, etc. cautions against an over-interpretation of results. However, a broad finding is that climate change has the potential to significantly increase damage costs from flood events in Nepal. For the catchments and models considered, the frequency of currently defined return periods are projected to occur more often, i.e. a high water level threshold that leads to floods-which might have only happened once every ten years previously (on average) -may happen every 2-5 years with climate change. Perhaps more worrying, is the frequency of major events, i.e. an event that previously might have only occurred 1 in every 100 years, might now occur every 20 or even 10 years with climate change, at least for some river catchments. The magnitude of events associated with given return periods thus also increases (e.g. a flow of 1000 m^3/s may have previously occurred once every 10 years on average, though this will increase to a flow of 1500 m^3/s once every 10 years with climate change). This is important because higher flows increase the damages (costs) of any individual flood event, as faster water flows, higher flood depths, and the larger areas inundated, will lead to more damage.

These results have been used to investigate the potential changes in impacts and economic costs from water-induced disasters. To do this in detail would require a very extensive study, noting that such an assessment needs to be carried out at a river catchment level, using bias corrected daily data in daily hydrological models to assess flow regime changes, and looking at the uncertainty across different climate models reflecting the very large changes seen above, combined with detailed vulnerability maps and loss probability curves/depth damage functions. The level of analysis required for such an assessment is extremely large. This is beyond the time and resources of the current study, but it is highlighted that there is work being undertaken towards such an analysis within the GFDRR and PPCR work (outlined in the box in section 4.3).

Nonetheless, it is possible to use the information above with the analysis of historical data sets and the current relationship between economic costs and indicative return periods (shown below, with the sum being the annual equivalent damage, i.e. US$266 million/year) to look at the potential change in high flows (and losses). The changes in return periods can be studied to adjust the loss – probability relationship to investigate the impact of climate change. It is stressed that this national scale analysis should only be considered indicative.

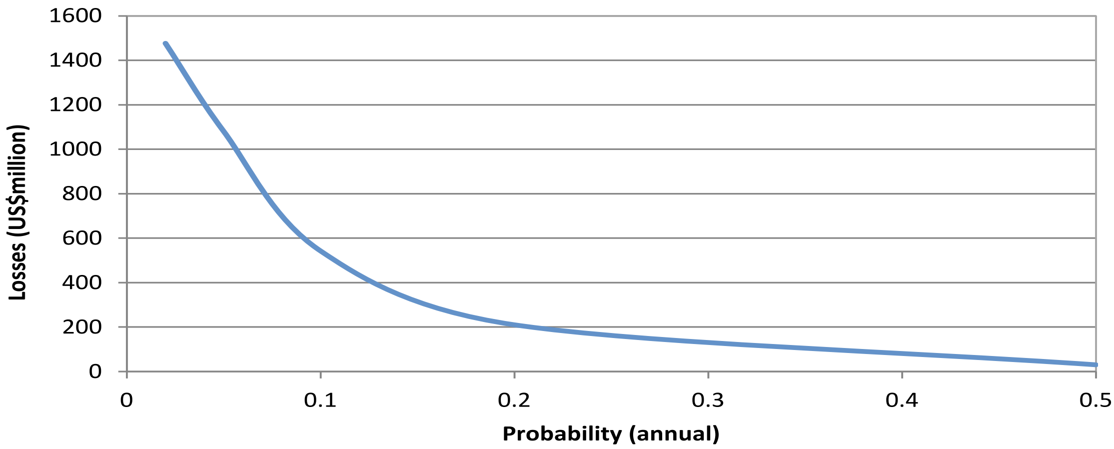


Figure 7.17. Historical national loss – probability curve (based on DWIDP data)

Source: Study Team.

The future analysis of climate impacts has used the range of potential changes in flow-probability, from different climate-hydrological model combinations and different catchments, to present the results as a range. While this has a large number of assumptions, and is not a substitute for detailed basin analysis, it is an indicative analysis of the potential increase in economic costs. Consistent with the approach outlined in Chapter 3 of this report, the Government of Nepal database has been complemented by data derived by the project team. Specifically, while the Government datasets provide information on property damaged and total losses, additional analysis has been undertaken to assess the potential economic costs for fatalities and injuries, livestock losses, and welfare losses from disruption, and as discussed in Chapter 3.

The analysis indicates the impacts of climate change (in terms of direct, economic costs on property infrastructure and welfare) are likely to fall in a central band of US$100 million to US$200 million/year (equivalent annual damage, current prices, undiscounted), equivalent to a central estimate of 0.6 to 1.1% of current GDP equivalent. However, the full range from the model-catchment combinations does indicate a larger range, equivalent to 0.3 to 2.7% equivalent of current GDP.

Importantly, the results only consider the direct economic costs (tangible and intangible) of these events. They do not include the indirect effects and the overall macro-economic costs. Indirect costs occur as a consequence of initial flood impacts and damages, e.g. business disruption and lost wages. Macroeconomic impacts include the aggregate impacts on economic variables such as GDP, consumption and inflation due to the effects of disasters, as well as the shift of government resources to relief and reconstruction. Assessing these additional impacts requires linked models, such as input-output catastrophe models or looking at the effects of shocks in CGE models, or otherwise ex-post assessments of major disasters. While it has not been possible to model these, comparison of similar events in other countries indicates that the total costs of water-induced disasters (i.e. including indirect and macro-economic costs, as well as direct and intangible effects above) are likely to be 25% to 100% greater than the direct costs above.

Finally, these values assume static socio-economic trends. The population and assets at risk will increase significantly in Nepal in the future: the increase in population alone would increase future risk exposure by over 30% by 2030 and 50% by 2050 and the increase in GDP/capita could be larger, increasing five-fold even by

2030, and almost doubling again by 2050. This has the potential to increase the economic costs significantly. However, rising wealth should increase adaptive capacity and should result in more autonomous and planned adaptation (to existing risks), thus reducing future risk levels, provided that these future risks are incorporated in development and land-use policy. This highlights the need for early adaptation.

Comparison with other studies

A number of other studies have investigated these effects. The NCVST study (NCVST, 2009) considered eight signature events of the recent past and looked at the consequences of these events with climate change. It reported that climate change could double the damage per household (for floods) and increase the number of households affected by 40%. The Lower West Rapti Basin (LWRB) study (see above) indicated a very large increase in future flood damages, with increases potentially of more than 50% and even as high as 200% in the far future.

Discussion of uncertainty and the effects on the sector results

The analysis here shows the choice of the driving Global Climate Model makes a large difference to the precipitation change and thus the hydrological analysis. While all the models - when used with a daily hydrological model - indicate increases in high river flows and a change in the return periods, there are large differences in the changes projected. There is an additional level of uncertainty introduced from glacial ice-melt and snow melt rates (see Chapter 5) which add a further layer of uncertainty to the results above. This highlights the need for enhanced monitoring and research.

There will also be changes from future socio-economic drivers, which will drive underlying exposure in terms of population and assets at risk, but potentially reduce impacts due to increased wealth and adaptive capacity (noting that future development has the potential to increase as well as decrease future risks, e.g. by increasing or decreasing construction in high risk areas).

Other risks to the sector

There are a number of related issues that are not captured in the analysis above.

One of the most important of these is the additional water-induced disaster risks from Glacial Lake Outburst Floods (GLOFs). Pokharel (2010) reports that there are 2323 glacial lakes identified so far, out of which 20 are identified as the most dangerous ones with potential risks of GLOFs, and highlights the risks of climate change in the creation of new glacial lakes and expansion of existing ones. However, the analysis of the risks of these events and their consequences is challenging. As highlighted by Matambo and Shrestha (2011), the impacts depend on factors such as the size and depth of the lake, the nature of the outburst, the geomorphology of the river valley and elements exposed to the flash flood, etc. Nonetheless, these floods could become an important additional water-induced hazard in Nepal, especially for moraine-dammed lakes.

In addition, the analysis above does not consider the increased risks of landslides and landslips from increased rainfall. While heavy rainfall and/or continuous high rainfall periods (waterlogging) are important factors in landslides, these are very site specific, depending on gradient, rock formation, soil, vegetation cover, management practice, etc.

7.6. Wider Economic Costs

The information above summarises estimates of direct economic costs, linked to physical outputs from the models. However, the effects of climate change will also lead to additional wider economic effects. These include indirect effects (multiplier effects) as impacts in one sector affect other sectors, and effects from changes to demand (for goods and services).

As highlighted earlier, we have identified where the inter-dependencies are strongest using input-output analysis and, therefore, where the impacts of climate change are most likely to lead to macro-economic effects, based on data from Raihan and Khondker (2011).

Backward linkages trace the output increases which occur in sectors that supply the given sub-sector, whilst forward linkages trace the output increases which occur in sectors that utilise the outputs of the given sector. Clearly, those sub-sectors that have the highest levels of linkages will have stronger effects on other subsectors and therefore potentially larger macro-economic impacts for a given output change. Table 7.6 and 7.7 list the economic sub-sectors that have the highest and lowest levels of backward linkages across Nepal's economy, respectively. The sum of the values for forward or backward linkages can be broadly interpreted as representing the size of multipliers associated with an injection or withdrawal into each of these sub-sectors. Assembling these results in a social accounting matrix, Raihan and Khondker (2011) show that the average sectoral multiplier is 8.9 (ideally the data would be analysed in relation to the specific impacts and sectors identified in this chapter, but this level of information is not currently available). The tables also give an indication of the main climate change impacts identified as potentially affecting the individual sub-sectors and an initial assessment of their significance to the economic activities within the sector, based on the team's own judgement. This provides a relative ranking of the level of linkage (from 1 to 5). It should be emphasised that the list of climate change impacts potentially impacting on each sector is not comprehensive in these tables. Consequently, these impacts do not explain the full range of forward and backward linkages that will exist. It is therefore likely that the combined effect of the multiple climate impacts will in each case be higher than the score given in the fifth column.

A further dynamic form of impact that may affect the indirect economic effects of climate change impacts is the effect of socio-economic change in future time periods. For instance, technological changes in production processes or changes in patterns of consumer demand may exacerbate or constrain climate change impacts, independently of adaptation initiatives.

Overall, the analysis indicates that the sub-sectors with the highest levels of backward linkages are likely to be more vulnerable relative to those with the lowest levels. An important factor in explaining this is that a number of the sub-sectors with the lowest levels of backward linkages are associated with resource extraction – activities that are expected to be relatively impervious to climate change impacts. Those sub-sectors that have high levels of backward linkages and who are expected to be most vulnerable to climate change impacts – e.g. leather, meat and dairy products – tend either to rely on water-intensive processes or who are at particular risk from climate-induced disasters. In contrast, the oil seed and fruit/vegetable sub-sectors are likely to be particularly vulnerable to a range of climate risks. However, their low levels of backward linkages imply that these risks are less likely to result in major macro-economic effects. In aggregate terms, the multiplier value of 8.9 presented above suggests that a climate change impact in a given sector may result in indirect effects in wider terms, equivalent to almost nine times the direct impacts that we have estimated. In due course, these observations should be supported and measured quantitatively through simulations of macro-economic models such as developed by IPRAD (Khanal, 2007). The size of these potential linkages highlights the need for further analysis into these potential indirect effects.

In the same context, it is important to note the importance of tourism for the Nepalese economy. Whilst not quantified here, tourism is likely to be impacted directly. For example, the expected and substantial elevation shifts of ecosystems and rising temperature and seasonal variability in precipitation may result in more rapidrecession of Himalayan glaciers thereby impacting tourism infrastructure. Indirect effects on tourism may result from changing patterns of food production and agricultural activities that affect food availability and prices for both local and tourist populations (Nepal, 2011). A recent study (Rayamajhi, 2012) confirmed the potential importance of climate change to the tourist industry in Nepal. It found that while 80% of surveyed tourists stated that increased risk of heavy or erratic rainfall could prevent them from visiting Nepal in the future, 74.3% said increased risk of landslides or floods could prevent them from visiting Nepal in the future.

Table 7.6. Mapping of Economic Activities with the Highest Backward Linkages against identified priority climate change risks

Sub-Sector	Backward linkages	Forward linkages	Climate impacts	Severity of climate impacts (1 - 5)
Leather products	3.9973	3.3142	Reduced reliability of water resources likely to increase cost of leather processing.	3
Meat	2.1834	1.0013	Increased disaster frequency likely to affect livestock directly through injury/death, as well as through affecting access to food.	3
Dairy products	2.1422	1.0906	As with Meat, above.	3
Drink and tobacco products	2.1060	1.3820	Crop productivity may be affected by changing rainfall patterns (e.g. drought) or disasters (e.g. floods). Reduced reliability of water resources likely to increase cost of production.	3
Construction	1.9750	1.0000	May be stimulated by demand for replacement following damage resulting from disasters.	1
Communications (IT)	1.9667	1.2813	Communication infrastructure may be damaged by disasters.	1
Timber	1.9641	1.0023	Timber production may be affected by more frequent landslips resulting from changing rainfall patterns.	2
Paper & paper products	1.9115	1.4427	Reduced reliability of water resources likely to increase cost of production.	3
Meat products	1.8790	1.0106	As with Meat, above, plus increased cost of production resulting from reduced reliability of water resources.	3
Non-ferrous metals	1.8478	2.3754	Transportation may be affected by damage to infrastructure from disasters.	1

Key
1 = small effect on sectoral output
5 = significant effect on output
Project Team, based on 1-O tables of Raihan and Khondker (2011).

Table 7.7. Mapping of Economic Activities with the Lowest Backward Linkages against identified priority climate change risks

Sub-Sector	Backward linkages	Forward linkages	Climate impacts	Rating of severity of climate impacts (1 - 5)
Chemicals & Rubber	1.1449	1.1253	Transportation may be affected by damage to infrastructure from disasters.	1
Road transport	1.1403	2.8631	Transportation may be affected by damage to infrastructure from disasters.	1
Gas production	1.1397	1.0296	Transportation may be affected by damage to infrastructure from disasters.	1
Vegetable & Fruit	1.1336	1.1009	Crop productivity may be affected by changing rainfall patterns (e.g. drought) or disasters (e.g. floods). Reduced reliability of water resources likely to increase cost of production.	4
Oilseed	1.1319	1.2854	Crop productivity may be affected by changing rainfall patterns (e.g. drought) or disasters (e.g. floods). Reduced reliability of water resources likely to increase cost of production.	4
Aggregates Mining	1.1234	1.0458	Transportation may be affected by damage to infrastructure from disasters.	1
Trade	1.1171	4.8301	Transportation may be affected by damage to infrastructure from disasters.	1
Machinery & equipment	1.0865	1.1067	Transportation may be affected by damage to infrastructure from disasters.	1
Wool	1.0739	1.0409	Crop productivity may be affected by changing rainfall patterns (e.g. drought) or disasters (e.g. floods). Reduced reliability of water resources likely to increase cost of production.	3
Petroleum	1.0597	1.0000	Transportation may be affected by damage to infrastructure from disasters.	1

Key
1 = small effect on sectoral output
5 = significant effect on output
Project Team, based on 1-O tables of Raihan and Khondker (2011).

Regional to Global linkages

It is highlighted that in some sectors – notably in agriculture and regional electricity flows – the economic costs of changes in productivity in Nepal will be heavily influenced by regional and global scale effects, and changes in production, prices and trade. While detailed regional or global modelling has not been possible, the study has considered the literature and available evidence and interpreted the potential effects.

7.7. Conclusions

This chapter assesses the future impacts of climate change, using scenario-based impact assessment, working with downscaled climate model projections and sector models.

The analysis in the agricultural sector has focused on the key crops in Nepal, i.e. maize, wheat and rice, using the DSSAT crop model. The results show a strongly differentiated pattern over time and across the country, with potentially high negative impacts from climate change in the Terai in later years (e.g. with yield reductions of 10% – 20%), but a varied pattern in the Hills and Mountains (including potentially high benefits, but also potentially negative impacts). The study also finds higher climate variability in some regions in the long-term, which would increase year to year variability in production. The study has valued these changes to provide analysis of the overall change in total production. The overall finding is that in the 2030s, there is an estimated net increase in production and economic benefits, but by the 2070s, there is an estimated decrease in most crops and high net economic impacts, estimated at US$140 million/year (undiscounted), which is equivalent to around 0.8% of current annual GDP. In extreme years, the effects of climate change will, however, be much more severe. The study has also considered the climate model uncertainty, noting large differences in key variables (rainfall trends and variability) between different models, which leads to a range of results including more positive outcomes but also possible severe impacts. A number of other potential impacts are identified including increased flood damages, increased soil erosion and the changing range/prevalence of pests/disease.

The analysis of the future impacts of climate change on hydro-electric power combined hydrological model runs with a hydro-electricity optimisation system (VALORAGUA and WASP), to consider the changes in river flows and energy generated. However, there were large differences found in the projections between different climate models and the study therefore compared two different data sets. The first model projected lower dry season flows and lower energy availability. The additional capacity needed to meet future demand under this scenario was estimated at an additional generation expansion costs of US$2.6 billion (present value) for the period through to 2050, relative to the baseline (i.e. an impact). This scenario also leads to increased level of thermal plant on the system, increasing GHG emissions. However, the second model, which projects higher river flows in the dry and wet seasons, leads to increased energy availability and avoids the need for additional plant, thus leading to a reduction of generation expansion costs of - US$170 million (present value) over the period to 2050 compared to the baseline (i.e. a benefit). There are also additional risks from increases in high flows and GLOFs, which lead to high additional impacts. The overall results indicate the potential importance of climate change on the sector is high, but also that there is considerable uncertainty over future changes, which vary by river catchment and over time. These are increased because of the additional (and uncertain) impacts of glacial melt water on flows. This uncertainty necessitates more monitoring and research, and a move to more flexible and iterative planning.

The analysis has also investigated the potential future impacts of climate change on water-induced disasters. The analysis shows most models project increases in the intensity and frequency of high flows with climate change, and thus higher risks of these events. The increase varies with the river catchment, climate and hydrological model, but as an example, current high flows (intensity) were found to increase by 20% -100% by mid-century due to climate change. At the same time, the return period current events (of a defined probability, e.g. 1-in-10 year event) were found to reduce. Importantly, the probability of an event with flows currently associated with very rare events (e.g. a 1-in-100 year event) could occur once every 10-30 years with climate change. The central estimate of the additional direct economic cost of climate change is US$100 million to US$200 million/year (equivalent annual damage, current prices, undiscounted), equivalent to 0.6 to 1.1% of current GDP equivalent. The total cost (including indirect and macro-economic costs) would likely be 25% to 100% higher. However, the full range is much larger, with an upper estimate of 2.7% equivalent of current GDP. The cost of these floods could also rise with growing population and assets at risk, though rising wealth should increase adaptive capacity and reduce future risk levels. The damage cost of events could also rise with growing population and assets at risk, though rising wealth should increase adaptive capacity and reduce future risk levels, provided that these future risks are planned in development and land-use policy.

The effects of climate change above will also lead to additional wider economic effects. These include indirect effects (multiplier effects) as impacts in one sector affect other sectors as well, and effects from changes to demand. There are existing results from an existing social accounting matrix for Nepal, which indicate a high average sectoral multiplier (of 8.9), suggesting an impact in a given sector may result in large indirect effects, however, more detailed analysis is needed to investigate these effects further.

The overall results show differences between the three major sectors considered. The impacts of climate change on the agricultural sector are potentially large, excluding autonomous and planned adaptation. However, the results are highly sensitive to future climate projections. For hydro-electricity generation, the impacts of climate change on river flows are likely to be highly significant, but there is high uncertainty on the exact changes and whether there would be positive or negative impacts that arise on generation levels. Finally, for water-induced disaster, for the catchments studied, there are negative impacts from climate change, with increases in high flows and reductions in return period, though again the level of change varies across models. The results indicate that the impacts of climate change on water-induced disaster are highest for the sectors considered.

Finally, the study has looked at the wider economic costs from climate change. An analysis of input-output tables for Nepal has identified the main linkages (forwards and backwards) and their relative climate risks. These show potentially important linkages that would increase the impacts above.

Overall, the analysis of future impacts shows that climate change could have potentially very large impacts on Nepal in the three sectors considered. When combined, study concludes that there are potentially high economic costs from climate change in Nepal. The direct costs from the three sectors could be equivalent to 2% to 3% of current GDP by mid-century (static assumptions), though more modest and more extreme outcomes are also possible.

8 Adaptation

Key Summary Points:

- The study has assessed the potential adaptation options to respond to the current and future risks identified in the agricultural, hydro-electricity and water-induced disaster sectors in Nepal. An initial review identified a very large number of potential options. The study prioritised indicative options by building an iterative adaptation pathway that starts with current climate variability and looks at future risks of climate change (including uncertainty).
- Work-stream 1 focused on adaptation options that address the current adaptation deficit, with the identification of capacity building and low-and no-regret adaptation options. In the agricultural sector, these centre on enhanced agro-meteorological information and forecasting, capacity building, and sustainable agriculture/climate smart agriculture. In the hydro sector, these are primarily based on improved management and retrofitting of older equipment in current plants, but also looking at demand efficiency. In the water-induced disaster sector, these centre on enhanced hydrological monitoring and forecasting, enhanced early warning systems, capacity building and governance, community based adaptation and people centred interventions, and ecosystem based adaptation. It is noted that many of these early options are already included in existing policies and programmes. The priority is therefore for scaling-up, enhanced techniques, and supporting capacity building and creating the necessary enabling environment to overcome barriers.
- Work-stream 2 has assessed the additional investment needed to mainstream climate in existing investment development profiles (public and private) up to 2030. This updates the baseline investment profiles. The total additional adaptation needs are estimated to rise to $290 million/year by 2020 and $530 million/year by 2030, with a total over the period of US$2.4 billion (present value, discounted), an increase of approximately 10% over and above the investment baseline. This includes approximately US$500 million for the hydroelectric sector, approximately US$1.7 billion for agriculture and approximately US$210 million for water-induced disasters (total present value). A sensitivity analysis has also been undertaken to capture uncertainty over the future climate risks, indicating that annual investment would need to double by 2030 under the high scenario. Importantly, the decision on which pathway to adopt should be based on the data and learning over the next few years. It is stressed that these future investment plans are indicative, i.e. they have not been built-up from a line by line analysis of individual options. The next step is to build such detailed sector investment plans, with analysis of the options, programmatic activities and costs.
- Work-stream 3 looks at the potential major risks of climate change to Nepal in the longer-term, noting the high uncertainty, and identifies iterative adaptation pathways. These allow a flexible approach, rather than selecting specific option that may or may not be needed. For agriculture, a key issue is to build the response capability to respond to increased risks and potential opportunities, with enhanced monitoring/research and pilot testing to develop capability, as well as integrated water resource management. For hydro-electricity, a clear priority is for enhanced risk screening to take account of

climate change in plant design, and for enhanced monitoring and research, including GLOF risks. For water-induced disasters, enhanced early monitoring and research is highlighted, alongside risk screening and integrated (sustainable) land use-planning, noting this requires early institutional strengthening. There is also a need for future flood defence infrastructure to be designed with flexibility in mind, and the development of non-technical programmes. The next steps are to build more detailed, costed iterative plans, and to start early programmes for critical early steps.

8.1. Introduction

The previous chapters outlined the potential risks and economic costs of current climate variability and future climate change in the agricultural, hydro-electric and water-induced disaster sectors in Nepal. The analysis shows that the impacts of future climate change could have very high economic costs to the country. While global emission reductions (mitigation) could reduce some of the most severe negative impacts in the later part of the century (after 2050), there will be significant impacts in the medium term (up to 2050) and beyond, even if ambitious goals to limit global average surface temperature increases to 2°C relative to pre-industrial are achieved. Furthermore, at the present time, international negotiations have had modest success, and the current commitments and pledges are not on track to achieve the 2°C goal (IEA, 2012).

Against this background, it is clear that adaptation will be needed in Nepal. Adaptation can reduce the risks of climate change, however it has a cost, and the level of adaptation needed will vary strongly with future climate change, noting the uncertainty presented in Chapter 5. Related to these points, there is an increasing recognition that adaptation assessments need to move from a theoretical analysis towards practical implementation, taking account of the effective use of resources in the context of existing development plans and future uncertainty.

The study has therefore reviewed the existing adaptation studies in Nepal, and developed a framework to order and prioritise these options. This presents the consideration of adaptation in a new way, which looks to build an overall pathway for adaptation based on the findings of the three work-streams, and addresses uncertainty using an iterative approach.

The chapter starts with a discussion of this methodological framework, followed by a synthesis of the review findings, and finally the development of adaptation pathways for each of the three major sectors of the study.

8.2. Methodological Framework for Adaptation

The methodological framework for the overall study was presented in Chapter 3. In the context of adaptation, three key issues have emerged in the recent adaptation literature:

- First, while long-term studies of the future climate impacts (and adaptation) are useful, there is a more urgent need to consider short term time-scales, wider (non-climatic) drivers, current policies, institutional and governance issues, and the dynamic nature of climate change–from short-term trends to future major climate change (Füssel and Klein, 2006). Climate resilience and adaptation needs to be integrated and mainstreamed within development plans, rather than being presented as a set of stand-alone actions.

- Second, there is a need to recognise that adaptation is a dynamic process, responding to the changing nature of future climate change. The literature identifies the need to start with current climate variability and the existing impacts of extreme events, and consider subsequent steps of building adaptive capacity, mainstreaming climate change into development, and tackling new longer-term challenges (McGray et al., 2007; Klein and Persson, 2008).
- Finally, future climate change is uncertain, and tackling it requires a new approach, which should look for flexibility and robustness rather than optimization, thus producing adaptation plans that are iterative and use a framework of decision making under uncertainty. This allows decisions to be made – and changed – as the evidence emerges. This leads to a view of adaptation as a pathway, and the use of such iterative risk management approaches (adaptive management) as highlighted in the IPCC Special Report on Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation (SREX, IPCC, 2012).

These issues lead to an overall framework for adaptation, based on taking the results of the three work-streams analysed in previous chapters, and then developing an iterative adaptation pathway (Downing, 2012). This has a more complex and dynamic view of climate change, bringing together these three evidence lines (over different time periods) in a way that has a strong economic rationale and also addresses uncertainty.

The adaptation pathway starts with responses to current climate variability and extremes (work-stream 1). This addresses the existing adaptation deficit and allows the identification of capacity building and early quick wins (no and low-regret options) that reduce current vulnerability and build resilience for the future, as well as the capacity building priorities.

In addition to this, it considers the future profile of development plans, grounding the analysis in the existing institutional landscape which will influence the development of Nepal over the next one to two decades, i.e. in the context of Government policies, and development and sector plans. The adaptation pathway takes the information on whether plans are resilient to address current and future climate change or not, and it also considers where adaptation is already happening, and where mainstreaming needs to be incorporated (work-stream 2).

Finally, it looks at the future challenges of climate change (work-stream 3), taking account of uncertainty, and identifying areas where early action might be needed now, to enable future decisions.

The overall framework is shown below.

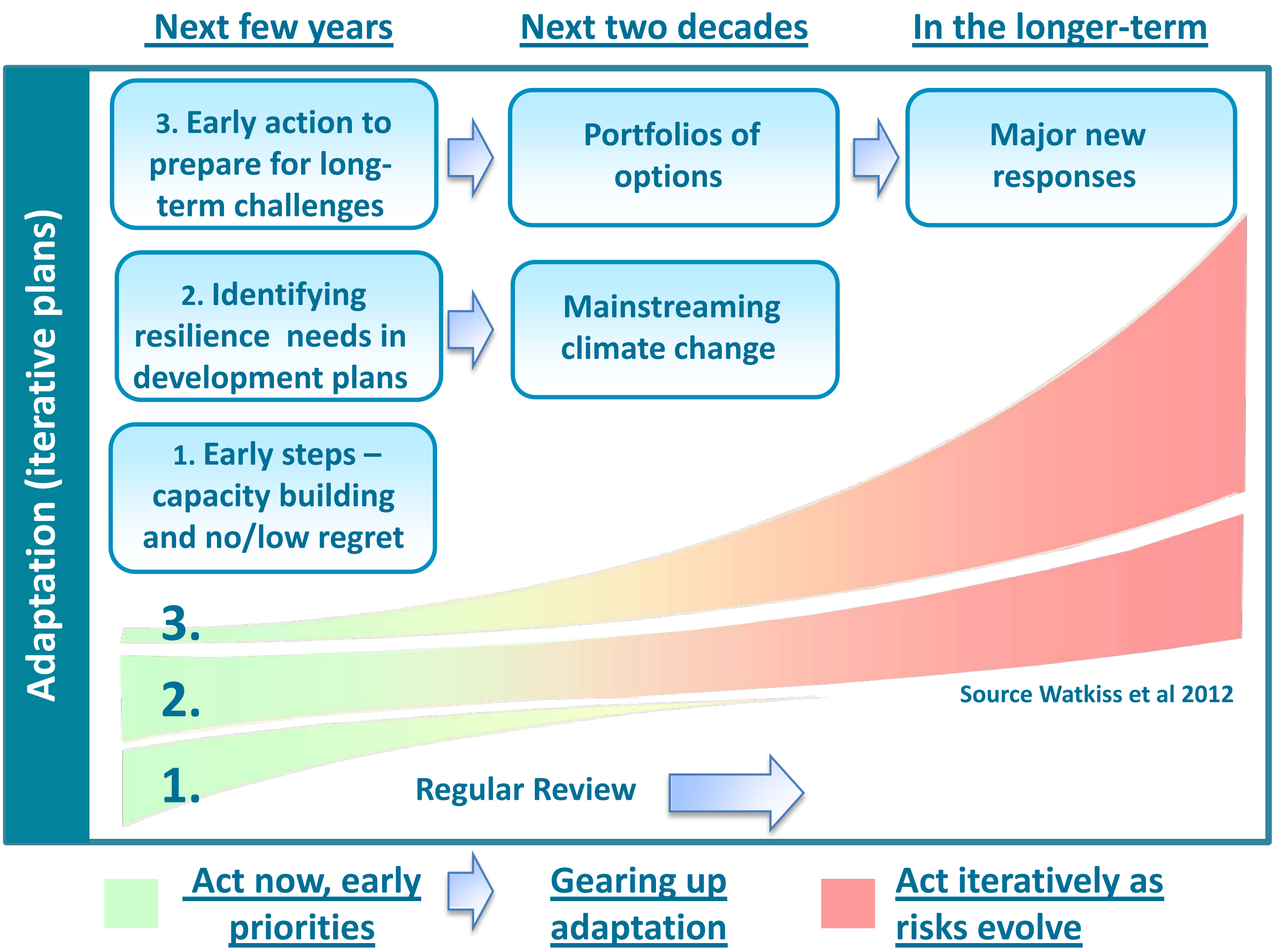


Figure 8.1. Iterative Adaptation Pathways

Source: Watkiss, 2012.

Priorities for Early Adaptation in Iterative Adaptive Management

Using this framework, the study has identified four priorities for adaptation to build up the adaptation pathway.

- Building adaptive capacity. This is important as a precursor to successful adaptation and low carbon growth, providing the necessary architecture to enable future decision making, provide baseline information to assess future benefits, and provide critical early actions to facilitate later options.
- Focusing on win-win, no regret or low cost measures which are justified in the short-term by current climate conditions (i.e. addressing current climate resilience and disaster risk reduction), or involving minimal cost. They also include options that provide positive ancillary effects (e.g. social or environmental benefits). For low carbon development, these options reduce emissions and have a positive net economic cost, such as energy efficiency. Finally, there are synergistic options, which provide both resilience and lower carbon emissions (win-win situation), and are an early priority.
- Mainstreaming involves assessing the current programmes in place, to consider whether these address existing climate variability and future climate change, and then look to address any gaps by incorporating

promising adaptation or low carbon projects. It can also look to build these aspects into policies and investments as they are developed. This can protect investment (e.g. infrastructure) that will be affected by future climate change through climate risk screening, i.e. to include resilience and low carbon opportunities at the development stage, or as part of renewal or refresh programmes.

- Identifying long-term issues that require early pro-active investigation or action. This includes a number of elements. It can include the planning for future major effects that require early investigation or planning due to the long time-scales involved. It might also include risks, which involve thresholds, or irreversibility, which require a more precautionary-based approach. Consideration of these longer-term issues may require early pro-active investigation (rather than early technical options) or initial short-term options that allow flexibility and robustness for the future, and avoid lock-in.

It is stressed that these activities are complementary and not a linear sequence (though there is a general time dimension from the left side to the right side). They involve a set of actions that address the present situation (and current climate variability) and move to issues that prepare for the future. Importantly, there will be feedbacks between them: as an example, failing to adequately build future climate change into current climate variability could lead to major impacts later and/or reduce the potential for change.

Building Capacity	Low-and no-regret options	Main-streaming	Addressing future challenges
Interventions that increase adaptive capacity, provide information, raise awareness, help institutions, address barriers.	Interventions that have benefits in reducing current climate risks, or are synergistic for both low carbon and adaptation.	Interventions that mainstream climate resilience into existing or near-term plants and investments, to reduce risks.	Early actions for future challenges, providing information for later decisions, or encouraging robustness and flexibility.

Figure 8.2. Priorities for Adaptation (iterative adaptive management)

Source: Watkiss, 2012.

8.3. Review of Adaptation Studies and Information in Nepal

There are a large number of existing studies (in the academic and especially in the grey literature) on adaptation in Nepal. Furthermore, the NAPA (GoN, 2010) identified a number of adaptation measures. An initial long-list was prioritized to produce a list of 9 options with an estimated budget of US$350 million. Five of these are particularly relevant for the study.

- Promoting community-based adaptation through integrated management of agriculture, water, forest and biodiversity sectors;

- Building and enhancing adaptive capacity of vulnerable communities through improved system and access to services related to agricultural development;
- Community-based disaster management for facilitating climate adaptation;
- GLOF monitoring and disaster risk reduction; and
- Empowering vulnerable communities through sustainable management of water resources and provision of clean energy.

There are also many studies at the sectoral level, which are summarised below.

Agriculture

There is a broad international literature on adaptation. Most of the analytical work, however, has focused on the use of crop models and farm level responses to long-term changes in climate change. These tend to focus on adaptation as a set of technical adaptation options involving crop switching, increased fertiliser use and increased irrigation (e.g. World Bank, 2010 Nelson et al., 2009). While these provide useful information, they do not address the issues of real adaptation for the agricultural sector.

A number of papers and studies have considered adaptation options for agriculture in Nepal (IIED, 2011; Sherchand et al., 2007; Malla, 2008; Rai et al.; Pokhrel and Pandey, 2011; Nayava et al., 2011; Thapa and Joshi, 2010; Pant, 2011; Lama and Devkota, 2009; Bastakoti et al., 2011).

Many studies have identified options based on techniques applied for general crop management. This includes the use of new crop varieties and livestock species (e.g. that are better suited to changed conditions), irrigation, crop diversification, adoption of mixed crop and livestock farming systems, and changing planting dates. Other studies also mention the use of climate information for planning (short-term and seasonal forecasts) and early warning systems, linkage with agricultural extension and agro-meteorological information, agricultural research, and capacity building and awareness-raising. Across the review of studies a number of agricultural adaptation options commonly emerge which include:

- Capacity building and knowledge, e.g. see box below.
- Disaster Risk Reduction (DRR), e.g. promoting crop insurance programmes, strengthening drought and flood early warning systems.
- Water supply and irrigation, e.g. developing small-scale irrigation and water harvesting schemes.
- Water related options, e.g. integrated water resources management, hydrological forecasting.
- Improving the natural resource base, e.g. agroforestry or sustainable land management.
- Improving transport and access to roads, e.g. increasing the length of paved roads, improving maintenance, and strengthening critical nodes and bridges.

Much of the recent literature reviewed has identified a set of options around sustainable agricultural land management (SALM) practices, which for example, adopt techniques to improve soil water infiltration and holding capacity, as well as nutrient supply and soil biodiversity, and include options such as agroforestry, soil and water conservation, reduced or zero tillage, use of cover crops, various soil and water conservation structures, and grazing land management. Many of these have also been cited as climate smart agriculture (climate compatible agriculture) as they reduce agricultural greenhouse gas emissions.

Similarly, the international literature highlights a range of prioritised measures to increase the productivity and resource efficiency of the livestock sector while addressing carbon emissions. These are related to increasing animal value chain efficiency in order to improve productivity. These include higher production per animal and an increased off-take rate, to support consumption of lower-emitting sources of protein such as poultry, to manage land to increase its carbon content and improve the productivity.

Capacity Building

Capacity building is a broad term (UKCIP, 2008) that involves: gathering and sharing information (undertaking research, collecting and monitoring data, and raising awareness through education and training initiatives); creating a supportive institutional framework that might involve changing standards, legislation, and best practice guidance, and developing appropriate policies, plans and strategies; and creating supportive social structures, such as changing internal organisational systems, developing personnel, or other, resources to deliver the adaptation actions, and working in partnership.

Typical examples include:

- Strengthening of meteorological and climate forecasting/projections.
- Enhanced monitoring (e.g. physical measurements such as hydrological flows, agricultural pests and disease, ecosystem health, etc.).
- Vulnerability or risk analysis and mapping.
- Climate information, knowledge and dissemination (including portals).
- Climate research programmes.
- Training.
- New (climate) institutional arrangements, etc.).

It therefore has strong overlaps with other options, either as part of complementary responses (i.e. investing in seasonal forecasts that help early warning systems) or as part of the evidence base for addressing future climate change.

An important finding from the literature - and reported in some studies in Nepal - is on the differing applicability of various technologies to specific risks and locations. Not surprisingly, this study finds that adaptation options perform differently according to region and agro-ecological zone. For example, some options (or sets of options) are more applicable for high rainfall areas (e.g. soil conservation) while others are applicable for low rainfall areas (e.g. water conservation). This provides an important feedback for adaptation planning as the effects of adaptation varies by region and location.

However, while there are a number of studies that list adaptation options, the quantitative analysis of these options are much more limited in Nepal, with a few limited examples using conventional farm management techniques in crop models (e.g. Rai et al.). There is very little cost-related information specific to Nepal, with only a handful of studies (seeIIED, 2011). A major gap therefore exists on the quantified analysis of a range of short-medium term measures, especially in the context of uncertainty, and their applicability to different agro-ecological zones.

Moreover, adaptation involves more than just technical options. Previous studies highlight that adaptation strategies are affected by informal and formal institutional support, provision of information on future climate change, and current levels of climatic variables. This shows that successful adaptation will require a move beyond a simple set of options, and needs to consider socio-institutional issues and capacity. In practice, adaptation will be governed by a host of factors. It is also highlighted that previous climate shocks have led to existing coping or adaptation strategies, particularly at farm level (i.e. autonomous adaptation) including migration (itself an extreme form of adaptation).

Hydro-power

There is a more limited literature on the adaptation options for hydro-power. Most studies highlight the need to raise awareness and research (inventories and monitoring of glacial lakes), land-use planning, early warning systems, though some also consider more extreme options such as system diversification (OECD, 2003). Other studies advance micro-hydro, which serves multiple rural development objectives, and could also help diversify and reduce GLOF hazards. An additional option mentioned is the potential for reducing existing electricity transmission losses, which are currently high, as a form of no-regret option, rather than building additional capacity to take account of potential future low flows. A number of technical options also exist to enhance production whilst building resilience, particularly built around retro-fitting to upgrade the efficiency of power generation facilities and offset any potential decrease in river flow.

Related to this, there are options identified for the broader adaptation of the water sector, which involve hydro-electricity. These include extensions of existing good water management practices, with options including awareness raising, research, more efficient management of existing water supply infrastructures; institutional strengthening; better hydrological forecasting systems and data collection/monitoring (including glacier and glacial lakes); strengthening of (integrated/sustainable) watershed management programmes; improved water management technologies (including the link to agriculture) and coordination of water resources development, as well as water conservation and use-efficiency improvements/loss reductions (WECS, 2011; Rees et al., 2004).

Water-Induced Disasters

There is a large literature on the potential for Disaster Risk Reduction, though this is based on addressing current extremes, noting that many of the same options are relevant in the context of future climate change (e.g. Heltberg et al., 2009; World Bank, 2011; IPCC, 2012).

These commonly include broad areas of prevention, preparedness and risk financing (e.g. Mechler, 2012), and include a very large number of options. This can include prevention and preparedness measures such as early warning systems, shelters and emergency responses, building codes and planning, and physical protection of infrastructure. In addition to these options are risk transfer and insurance, including micro, hazard and index based insurance, as well as national or regional schemes addressing low frequency, high impact events. Supporting this is a large number of capacity building and awareness raising activities, such as enhanced meteorological and hydrological information, institutional strengthening, etc. and broader linkages to integrated disaster, water and land management.

There are some studies that have looked at the costs of such measures in Nepal, notably the Risk and Resilience (2009)/NCVST (2009), and costs were considered as part of the NAPA.

As with the agricultural sector there is a more recent focus on broader sustainability objectives including ecosystem services. As an example, the ADB PPCR (2011) is advancing climate resilience in mountain regions through watershed management to reduce erosion and downstream sedimentation, enhancing soil moisture and groundwater recharge, and enhancing surface water conservation and storage, through specific adaptation options such as rehabilitating degraded watershed lands, regenerating forests, implementing conservation farming, protecting water infrastructure from erosion and floods, constructing or improving small-scale water storage facilities and distribution systems, and applying on-farm water conservation.

Discussion

The review of existing adaptation options has identified a very large number of potential options - both internationally and in Nepal - that would be relevant for addressing the risks of climate change. The full list runs to hundreds of options, and include a very broad range of adaptation (from autonomous farm or household level to national strategies), with technical and non-technical options, and different implementation models (market-based, public or private).

It is important to move beyond this long-list to identify priorities. At the same time, there is a need to look at the practical issues in progressing adaptation in Nepal, in terms of the institutional landscape, the alignment with existing policy and development objectives, the need to align possible projects or programmes to opportunities for finance, and to ensure there are concrete actions that are prioritised and implementable on the ground. However, the identification of future options is made more difficult by the high uncertainty in future impacts, and the strong differences in the risks and adaptation needs across the country, e.g. between the plains, mid-hills and mountains, between individual agro-ecological zones (and sub-zones), etc. A one-size-fits-all approach is likely to be inappropriate because of these differences.

It is also highlighted that many of the promising adaptation options identified are already being implemented, at least partially, in the various policies, programmes and projects in Nepal. A key issue is to build on these activities, and identify why some potentially promising options have not been implemented already, particularly those that address the high current climate variability. This involves addressing potential barriers, and highlights the complex issues of socio-institutional processes as well as technical options.

Addressing all of these issues is a huge undertaking, and will form the basis of the on-going national and local adaptation planning work (e.g. implementing the NAPA and LAPAs, and progressing to National Adaptation Plans and financing). While it is not possible to address all of these issues in this study, it is, however, possible to provide some analysis of potential adaptation options across the three work-streams

- with a focus on providing economic information. This provides a complementary set of analysis to the existing studies. The analysis is set out for each of the three work-streams in turn, using the iterative method outlined above.

8.4. Work-stream 1: Addressing the Adaptation Deficit

The two areas of focus in work-stream 1, which is associated with the existing adaptation deficit from current climate variability, is to build capacity and implement early priorities of low-and no-regret options.

There is a well-accepted definition of no-regret adaptation options (e.g. IPCC, 2007: 2012), which is around projects or policies that generate net social and/or economic benefits irrespective of whether or not climate change occurs, i.e. that are good to do anyway. There is a much wider range of definitions of low-regret options. These include (Watkiss et al., 2014):

- Technical options which look no-regret, but have opportunity, transaction or policy costs.
- Non-technical options, particularly capacity building, which provides information, monitoring, research, awareness raising, institutional strengthening, etc., to improve risk management and decision making, noting these generally involve relatively small costs.
- Options that provide additional ancillary benefits (notably environmental or social).
- Options where costs are low and there are high immediate benefits. Variations of this include where benefits are high but arise in the future.

There is also a set of options that are low regret but associated with future mainstreaming and early planning activities for future risks (e.g. work-stream 2 and 3), such as included adaptation in the design phase, in on-going replacement or renewal cycles, and through the introduction of flexible or robust options. The study has reviewed the adaptation options identified in Nepal, to try and identify early adaptation priorities, e.g. reviewing the available information to identify low-and no-regret options.

For agriculture, there is a set of activities around capacity building, many of which have been identified in the various documents cited above. These include better meteorological and agro-metrological data, including data collection, monitoring and forecasting capability, and early warning systems. It also included agricultural research and development and enhanced extension services, including raising awareness to build adaptive capacity as a means of reducing exposure. Much of the literature highlights that this should include local and community institutions, farmer to farmer level, and strengthening local level leadership and awareness.

There is also a large set of low and no-regret options. First, there are a large number of agricultural development activities including agricultural techniques and management options, e.g. better seeds, more climate resilient and pest resistant crops, improved livestock (productivity, pest and disease resistance), better farm management practices, addressing post-harvest losses, improvements across the value chain (e.g. access to market, rural roads, etc.). They contribute to improved yields and provide general enhanced resilience, but they are primarily development options, and are captured in existing agricultural development activities. As a result, the main focus for low and no-regret options is in relation to the adaptation deficit, and the risks of inter-annual variability and extremes.

One of the main low -regret options is climate smart agriculture, which builds on existing sustainable agricultural land management (SALM) practices (FAO 2011). These include techniques to improve soil water infiltration and retention capacity, as well as nutrient supply and soil biodiversity. These improve productivity, and address current climate related risks in the form of rainfall variability, as well as building resilience against future climate change. They include conservation agriculture (reduced or zero tillage, intercropping, use of cover crops or crop residues, to increase water retention and improve soil structure), agroforestry (which increases soil fertility, water holding capacity, and reduces soil erosion), and soil and water conservation measures (including structures- noting that soil conversation measures have high applicability for Nepal due to the more hilly terrain and the potential for soil erosion-or management practices such as rainwater harvesting). All these options reduce carbon emissions, e.g. by minimising soil disturbance and/or sequestering carbon, and thus have synergies with greenhouse mitigation and low carbon development. There was considerable support for soil and water conservation during the stakeholder consultations.

Many of these climate-smart options have been tested and/or traditionally applied. The priority is therefore for significant scaling-up to wider areas and through the introduction of enhanced techniques. A key priority is to develop the evidence base for these climate-smart measures, to pilot the most promising practices, and increase adoption and general innovation in the farming practices, coupling this with awareness raising and extension support (see above). There is also a need to address the barriers to enhance the uptake of these measures, noting specific issues, opportunity costs and access to finance, value chains and broader issues. It is often reported that many early agricultural adaptation options, particularly climate smart options, are ‘no regrets’, i.e. they have positive returns (as a net present value). However, recent work highlights that transaction and policy costs, as well as potential barriers, have not yet been factored into such assessments (i.e. for climate smart agriculture) and increase the costs of these measures considerably (McCarthy et al., 2011). Given the pay-back on many of these schemes is long-term (in the form of long-term soil improvement) they are likely to require planned support and awareness raising to address barriers to implementation.

There is also a strong geographical difference in the applicability of these options across the country, which means a differentiated strategy is needed, reflecting the different risks in the mountains and hills (from high gradients, and thus soil protection) from the Terai, where flood risks and inter-annual variability in rainfall are more important.

For hydro-electricity, there is less literature. There are some fairly no-regret options involved with the improvement of hydro-plant management and maintenance, and the retrofitting of older equipment with more efficient new turbines. Given projected increases in demand (and the fact that outages are likely to continue in the short-term), a focus on transmission losses and demand side management is also highlighted. This involves reducing the high current transmission losses in the distribution network and addressing the low efficiency of domestic appliances and service/ industrial use, i.e. energy efficiency. This provides an obvious synergy with climate compatible development.

There is more information onwater-induced disasters, and some existing information for Nepal, though this is based around current disaster risk management - rather than on the combined effect of current and future climate change - although given the changes projected in work-stream 3, climate change is likely to increase the economic benefits of early DRR.

NCVST (2009) reported that autonomous adaptation had a higher benefit to cost ratio than embankment building (based on analysis in the Rohini basin) but that structural measures were cost-effective in densely populated areas. It highlights the options of forest buffers, raising of houses, early warning systems (EWS), and expansion of local coping strategies (e.g. boats) for adaptation to floods. Importantly, it also highlighted that some adaptation options are path-dependent and irreversible (e.g. embankments) and therefore lock-in decisions (rather than providing more flexible approaches).

The Risk to Resilience Study (2009): "Catalysing Climate and Disaster Resilience: Processes for Identifying Tangible and Economically Robust Strategies" looked at the options for reducing flood in India, Nepal and Pakistan. It found positive benefit/cost ratios for an array of interventions that included insurance, early warning systems, local village-level responses, and large-scale infrastructure. Return rates were often higher when the impacts of climate change were considered, particularly for strategies that are resilient in the face of uncertainty. Return rates were particularly robust for the lower-cost people centred interventions that reduce the risks associated with high frequency, low magnitude events rather than those associated with large disasters. The economic benefits from interventions that required high initial investments and were targeted at less frequent but more extreme events were found to be less robust. These are particularly vulnerable to assumptions regarding the appropriate discount rate to use, and to uncertainties regarding the frequency and magnitude of extreme events, especially under a changing climate. Investing in low-cost forms of risk reduction that are designed to increase the resiliency of livelihoods, housing and other infrastructure at the household and community levels were among the most cost-effective avenues for reducing risks and thereby for supporting adaptation, though the report cautions that investments should not be directed away from lower frequency-higher magnitude disasters that can set individuals, households and regions back by many years. Instead, it implies the need for a balanced approach that combines sustained attention to small disasters in addition to extreme events with a large-scale, higher-profile impact. The study also emphasised the need for a balance of hard and soft measures.

A wider review of the international literature provides additional information. Mechler (2012) undertook a systematic review of disaster risk options and economics, and concluded that on average, the benefits of DRRare around four times the cost. This was based on 16 ex ante and 20 ex post studies (covering earthquake, flood, drought and windstorms – though the values for floods was 4.6 - similar to the overall average). A number of other studies also highlight potential low - regret options (Ranger and Garbett-Shiels 2012; IPCC SREX, 2012; World Bank, 2009a; 2009b), and economics of disaster and effective prevention study (World Bank, 2009). These broadly identify the following interventions as being no-or low regret:

- Enhanced meteorological services, monitoring, forecasting;
- Enhanced hazard and vulnerability mapping;
- Enhanced evacuation plans and emergency infrastructure (shelters, rescue centres);
- Capacity building and governance;
- Preparedness and awareness raising;
- Early warning systems (including the rapid transfer of information to community level using SMS technology);
- Better maintenance e.g. of existing river flow, drainage and sewerage systems;
- Enhancing design standards in new buildings and infrastructure including building codes;

- Integrated land-use planning and integrated coastal management zones/integrated water basin management, including potential for restrictions for high vulnerability;
- Ecosystem based adaptation (e.g. including upstream forests);
- Risk transfer (insurance, risk pooling) including weather based insurance;
- Livelihood diversification and asset protection;
- Social funds and safety nets (including early response).

It is stressed that these options span the range of risks, from frequent small-scale events to large-scale infrequent events. It is highlighted that the costs of these options does vary on a site-specific basis, and in terms of whether all opportunity costs are included, e.g. the opportunity costs of land in planning restrictions, new ecosystems, etc. but also whether all benefits are included (especially non-market sectors and the value of health protection and ecosystem services). There is a broad agreement that depending on the risk baseline, hard infrastructure may not be a low-regret option in the face of uncertainty (i.e. it is high cost, and can be low regret, though in some but not all cases). What does emerge is that infrastructure investment is best initially prioritised in protecting key critical infrastructure, e.g. hospitals, water supply and sanitation, etc. which provide key protection in post flood events.

It is noted that many of these early options - across all areas (agriculture, hydro and water-induced disasters) are already included in existing policies and programmes, or have been trialled. The priority is for scaling-up and also the introduction of enhanced techniques (i.e. ensuring good practice). This requires supporting capacity building (information, awareness raising and education, monitoring, institutional strengthening, research and pilots). It is also highlighted that there are some barriers to the introduction or uptake of many of these early options, including opportunity or policy costs, and they are therefore unlikely to happen autonomously. There will thus be a need to provide the necessary enabling environment (support, policy incentives, etc.) and planned support.

A priority is to undertake a detailed mapping of existing adaptation and resilience building activities across Government programmes and other activities (DP, NGO and private) and to i) identify key gaps and priorities ii) assess the activities and actions that need strengthening (including the need to scale-up to address emerging climate change) and iii) to then build up mainstreaming priorities as part of sector adaptation investment plans (noting this follows the process in the National Adaptation Plan framework). Similar activities have been undertaken in other countries, e.g. in Ethiopia, as part of the CRGE, and in Tanzania in the agriculture sector.

8.5. Work-stream 2: Adaptation Investment and Mainstreaming

Work-stream 2 has extended the analysis presented in Chapter 6 and built an adaptation scenario, to reflect the potential changes needed in investment and financial flows under climate change.

It is stressed that these future investment plans are indicative, i.e. they have not been built up from a line by line analysis of individual options, but have instead focused on the uplift to existing programmatic spend, taking account of the likely additional costs involved in mainstreaming (noting these broad uplifts are based on bottom-up analysis of the additional costs of options in specific sectors).

The level of additional adaptation required varies according to the future risks and impacts of climate change, but also on the level of existing and planned mainstreaming already in GoN policy and programmes (outlined in Chapter 6). Therefore in sectors where mainstreaming is already occurring, incremental costs will be lower. To address the uncertainty associated with climate change, three future scenarios are compared, related to low, high and central projections of climate risks.

For hydropower, the analysis in Chapter 7 assessed the additional investment in plant capacity to address changes in low flows from climate change. This related to a range of values, with additional generation expansion costs of US$2.6 billion (present value) for the period through to 2050 from one model, but a reduction of generation expansion costs of -US$170 million (present value) over the period to 2050 compared to the baseline (i.e. a benefit).

Based on this analysis, an additional capacity investment of 5% has been considered for 2030. In addition, the increase in high flows and river floods (see Chapter 7) indicates rising flood frequency and intensity, which means facilities need to be planned with greater capacity for high flows. Based on discussions with APEC, the additional costs to build this headroom is estimated at 10% to 15% per facility, though not all facilities will require resizing, thus we conservatively estimate an additional 10% increment for overall baseline investment. On this basis, the total additional costs of adaptation for hydro-power represent approximately US$500 million (discounted) above baseline for the period 2014-2030 of which USD US$200 million falls on the public sector budget.

For agriculture, the additional costs are associated with the need to invest in a wide range of programmes, to enhance irrigation in response to climate change (see Chapter 7) and are estimated at 10% by 2030. On this basis, the total additional costs of adaptation for the agriculture and irrigation sector represent approximately US$1.7 billion (discounted) for the period 2014-30, of which US$370 million falls on the public sector budget. Note that this is in addition to the significant levels of resilience mainstreaming already within the budget of the Ministry of Agricultural Development, estimated at a minimum of 30% of the baseline budget.

For water-induced disasters, the additional costs of adaptation are associated with the need to address the increased likelihood and intensity of flood events due to changes in monsoon precipitation, and potentially the increased risk of GLOFs under more rapid glacial melt. The analysis indicates an increase in budget of 65% by 2030. On this basis, the total additional costs of adaptation for the water disaster sector represent approximately US$209 million (discounted) for the period 2014-30, of which the majority falls on the public sector budget.

The total additional costs is estimated to be US$2.4 billion (discounted), representing an increase of approximately 10% over and above the envisaged investment baseline.

Summary of baseline and additional costs of adaptation by sector (US$million) - total over the period (discounted).

Table 8.1. Baseline and adaptation scenario by sector USD $m (discounted 2014-2030)

	Baseline Scenario	Additional Adaptation	Adaptation Scenario	New Adaptation $ as %
Hydropower	4955	496	5451	10%
Agriculture and irrigation	16989	1699	18687	10%
Water based disasters	321	209	530	65%
Total	22265	2403	24668	11%

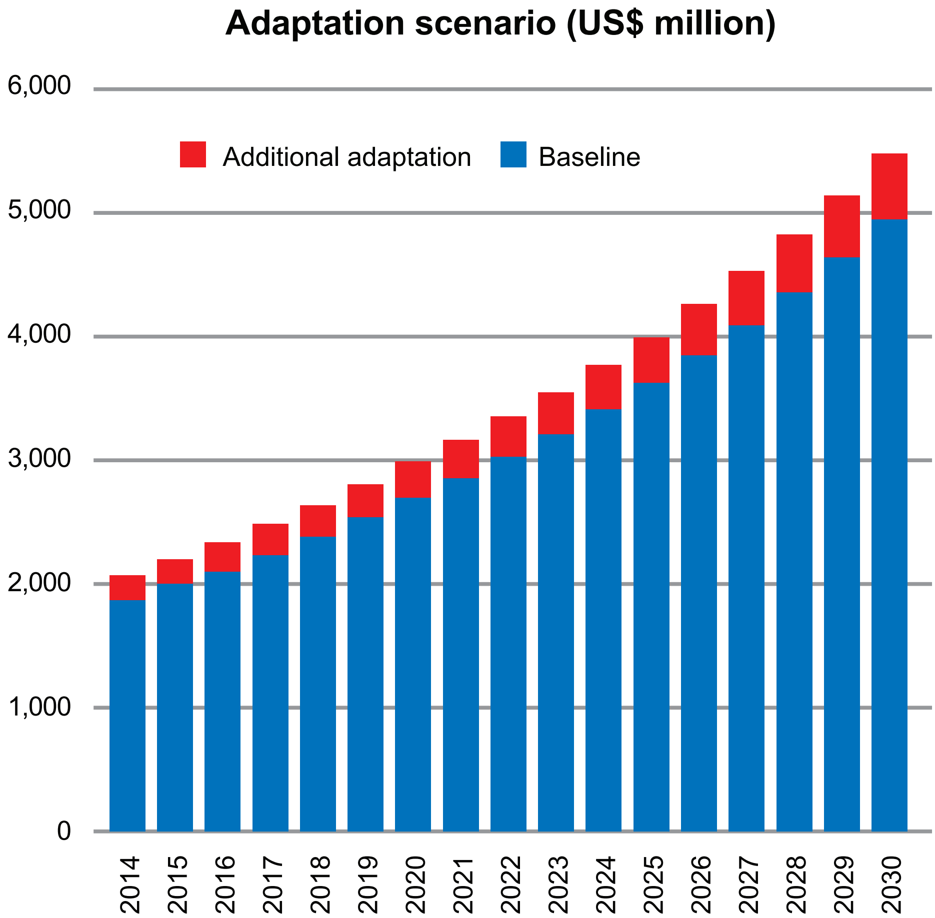


Figure 8.3. Adaptation Scenario

Source: Project Team.

Finally, a sensitivity analysis has been undertaken to capture the uncertainty over the future climate risks (as well as existing mainstreaming levels). Matching the low and high scenarios outlined for risks, the IFF analysis has considered two scenarios. Under both scenarios, the amount of early investment in capacity building and iterative scale up will be similar up to 2020, due to the current adaptation deficit and the need to address the drivers of vulnerability in the sector. However, after 2020 the additional investment outlined above changes according to two scenarios:

- The high-risk scenario corresponds to the more extreme scenarios of climate change (e.g. hotter scenarios, with greater variability and extremes, particularly larger increases in monsoon rainfall). Under this scenario, the existing mainstreaming of resilience and the additional investment in adaptation would need to be scaled up, to make sure that existing resilience gains (against the adaptation deficit) are protected, and most importantly, to develop the portfolio of adaptation measures to address future major risks in the period 2030 onwards. This high scenario assumes a higher investment level is needed for resilience, and thus factors in a higher level of investment growth in additional adaptation.

- The lower risk scenario assumes that climate change turns out to be at the lower end of the future risk profiles (e.g. with lower relative rises in temperature, modest changes in precipitation and no changes in variability or extremes). Under such scenarios, the level of future risks is lower, and less of the additional future portfolios are needed early on. Investment in adaptation activities grows more slowly than the overall water sector related budgets in the period post 2020.

Importantly, the decision on which pathway is needed should be based on the data and learning amassed over the next few years, consistent with the iterative risk management approach, and this highlights the need for early capacity building and enhanced information and research over the next decade.

Under the high impacts scenario, we estimate that the growth rate for additional adaptation spending will be higher than under the central scenario to address the upper range of damage cost projections. The increase in this growth rate results in additional costs of adaptation rising to 20% above baseline by 2030 (vs. 10% under the central scenario) for the hydropower and agriculture sectors. For water-induced disasters, the additional costs of adaptation rise to around 100% above baseline (vs. 65% in the central scenario). Under the low impacts scenario, the additional costs of adaptation rise to 5% above baseline by 2030 for hydro-power and agriculture, and around 40% above baseline for water-induced disasters. The total adaptation investment increases from US$530 million/year by 2030 under the central scenario to US$1046 million/year by 2030 under the high impacts scenario and reduces to US$294 million/year under the low impacts scenario. The actual additional costs of adaptation will be determined by the climate outcomes and the degree of effectiveness in mainstreaming resilience in the underlying policies and programmes.

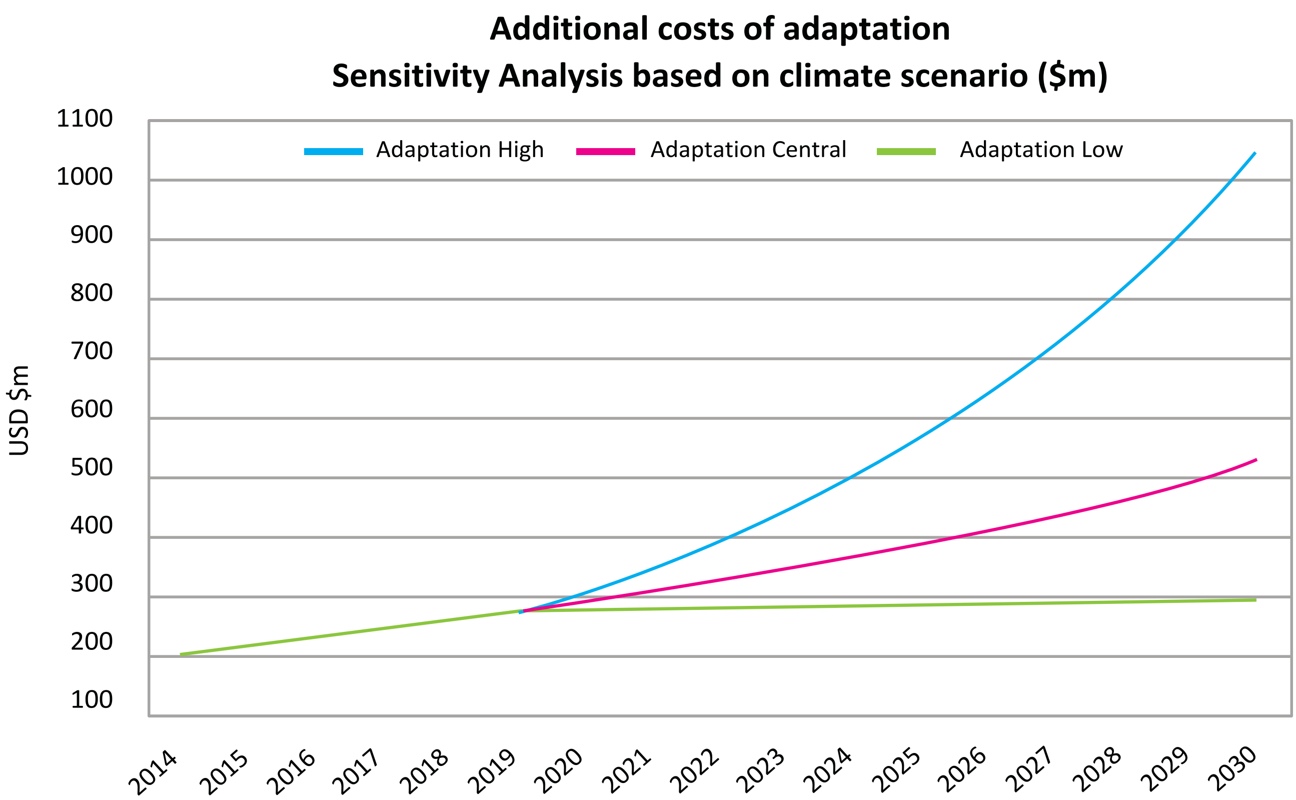


Figure 8.4. Sensitivity analysis under different climate scenarios

Source: Project Team.

The next step is to build detailed sector investment plans, which undertake analysis of the options, programmatic activities and costs involved.

8.6. Work-stream 3: Long-termIterative Adaptation Pathways

The final set of analysis regards the long-term risks of climate change, as identified in work-stream 3 and the scenario based impacts (Chapter 7).

This recognises that there are a number of longer-term major impacts that climate change could cause in Nepal, which would affect key growth, development and social protection objectives in the period beyond 2030. However, related to the projections of climate change in Chapter 5, there is high uncertainty around these future effects. It is not economically efficient to look towards optimised responses to central projections (or single model projections) for such impacts, especially if costs are likely to arise in the short-term, but benefits only accrue in the long-term.

To address this, the study has developed the concept of iterative adaptive management, building on recommendations from the IPCC AR4 (and the Act-Learn-Then-Act Again approach), the UNFCCC review of the economics of adaptation (UNFCCC, 2009), and the IPCC Special Report on Extremes (IPCCC, 2012). These build on the approaches developed on iterative risk management at the project level (e.g. the Thames Estuary 2100 project, EA 2009: 2011), which are also now starting to be translated into national level adaptation planning (e.g. Watkiss and Hunt, 2011; Watkiss, 2013).

These generally identify long-term risks (and if relevant, risk thresholds) and assess options (or portfolios of options) that can respond to these threats, accompanied by monitoring plans that track key indicators, and through a cycle of evaluation and learning, allows the adjustment of plans over time. The results of these iterative assessments are often presented as adaptation pathways or route maps.

The advantage of the approach is that rather than taking an irreversible decision now about the 'best' adaptation option – which may or may not be needed depending on the level of climate change that arises - it encourages decision makers to ask "what if" and develop a flexible approach, where decisions are made over time, and these plans adjusted as the evidence emerges (Reeder and Ranger, 2011). This allows that the right decisions are taken at the right time - such that additional options can be brought forward – or delayed to a later time period, depending on how climate change actually evolves.

A key outcome of such an analysis is to identify the early actions that are needed - over the next few years – to start planning for these long-term risks. This provides an explicit link between long-term risks to the early implementation of adaptation options as part of near-term adaptation investment.

For agriculture, the major risks were identified around potential large-scale reductions in productivity, especially in the Terai, but there are also potential opportunities from shifts in climatic zones and growing seasons to the hills and mountains. A number of farm level responses can address many of the risks/opportunities, but these require enhanced research and pilot testing, e.g. for new cultivars or crops, noting these take time to develop, test and roll-out. There are also the potential changes in pests and diseases, which could be particularly important for the hills and mountains. An obvious early adaptation priority is for enhanced monitoring of current pests and diseases, aligned to improved climatic data and shifts, to identify potential changes in prevalence or range early on. It is emphasized that reducing the risks and taking advantages of the shifts in climatic/agro-ecological zones will require long-term land use planning, to ensure areas that are potentially suitable for future agriculture are not lost irreversibly, e.g. to urban settlement.

A likely response to changes in temperature and variability in Terai will be for more irrigation. As highlighted in the baseline investment and financial flow analysis, there is likely to be an increase in irrigation in Nepal anyway, thus the likely adaptation response will relate to the higher extraction and application of water (rather than additional irrigation infrastructure). The potential yield reductions from climate change in the Terai reported in Chapter 7 indicate the increase in water demand could be important even in the 2030s. This highlights an important issue of cross-sectoral water management, and there is an early priority around integrated water resource management, which requires better information and monitoring but also institutional strengthening. There are also potentially large risks from increased flooding, particularly for the Terai, though this is discussed in the water-induced disaster discussion below.

For hydro-electricity, the major risks considered in Chapter 7 were around reduced low water flows and increased high water flows. In addition, a major potential risk not quantified (but considered important) is the potential for major glacial lake outburst floods, particularly as these could result in the irreversible losses of major capital investments. However, as highlighted in chapters 5 and 7, there is very high uncertainty around future impacts, threshold levels, etc.

Clearly a major priority is the need for enhanced monitoring, hydrological modelling and research. This has already been highlighted as a priority (e.g. GLOF monitoring is included in the NAPA and there are major research initiatives already underway). However, given the time periods (decadal) needed for reliable data sets and to reliably inform future design, a greater urgency is needed to expand this information base as quickly as possible.

For hydro-electric plants - especially in relation to the large increases in capacity anticipated over the next 15 years - there are important issues because of the very long life of the plant (e.g. 100 years). New hydro capacity will therefore be exposed to the future hydrological patterns with climate changeover the century, especially in the latter part of the period (after 2050) when large changes are anticipated.

There is a need for a much higher degree of climate risk screening in the development of all future plant with climate change incorporated in overall system planning (noting the link to the need for enhanced monitoring and research above, and also the analysis in work-stream 2). However, at the current time it is not possible to know the exact nature of changes, and thus there is a need to focus on low cost over-design or to build flexibility into the design and planning of the plant. This might include, for example, a higher design standard to cope with monsoon related high flows and surges, a greater awareness of mudslide risks and sediment loads, enhanced spillway capacity (or emergency spillway facilities), etc. It also requires design to ensure that generation equipment can operate robustly over the range of conditions that could be expected, noting this could involve reduced low flows and higher high flows. It is highlighted that any over-design is likely to have cost implications, and a key focus is for analysis to identify where over-design, or added flexibility or robustness, can be incorporated at low cost.

In terms of portfolios of options, a further set of options do exist around supply diversification, noting that this will lead to higher marginal costs of generation compared to large-scale hydro, i.e. it is not a least cost solution. Previous studies have highlighted the potential for small-scale or even micro-hydro as a risk diversification strategy (especially in the context of GLOFs) but given the high demand projections for Nepal, it is doubtful that micro-hydro could fill the demand gap that large hydro is projected to fill. A further diversification strategy is to introduce more thermal plant on the system, to avoid low flow risks and flood/GLOF risks, but this has a significant penalty in the form of increased greenhouse gas emissions, i.e. it is not consistent with a climate compatible development strategy. This shows that these diversification strategies should only be considered if major risks are likely (as identified through enhanced short-term monitoring) or if they are more cost-effective than risk protection and resilience measures for large plant.

Finally, the discussion above has focused on the supply side. There are also important issues on the transmission and demand side for electricity, which need to be considered in parallel. First, future climate change will change the electricity demand profile for Nepal, especially in the context of rising growth and incomes. Cooling demand during hot periods will increase, which is delivered by electricity. Heating demand during colder periods will also decrease, but this is delivered by a combination of fuels. An urgent priority is to assess the potential changes of climate change on electricity demand, and use this to re-assess future demand projections. There are also a large number of energy efficiency and planning/design issues (for buildings and appliances) to reduce future end-use demand. It is stressed that short-term energy efficiency has the potential to buy more time for decisions–

by reducing the need for early additional capacity - to allow better information on future risks and so allow a more resilient orientated response. It is therefore considered a priority (especially given energy efficiency is a no regret option, with net positive social present value).

For water-induced disasters, the major risks relate to potentially large increases in the frequency and intensity of flood events, as well as additional risks from GLOFs. Again, the uncertainty in future projections are high, and thus a priority is for enhanced data collection, monitoring, modelling and research.

Alongside this, there is a priority for more advanced risk and hazard mapping analysis, noting the major steps taken in Nepal in recent years with the GoN, EFDRR, and PPCR initiatives, as well as initiatives in the National Planning Commission. Important issues relate to the need to incorporate climate change within these processes (noting the uncertainty highlighted in this report) but to also translate that into national and local land-use planning, to reduce future risk and exposure of settlements, critical infrastructure, etc. and to help steer development to less vulnerable areas (reducing future exposure). This is likely to require planning rules/building codes and enhanced enforcement, and the challenge of these in a rapidly developing country should not be underestimated (nor the opportunity costs of some options) and the need for early institutional strengthening in these areas is critical. However, given population projections and the likely increase in assets, sustainable, integrated land-use planning is a key priority for reducing the lock-in of development to future risks. It is also highlighted that there is a need for integrated land-use planning to ensure potential risks are not made worse, e.g. through land-use change and deforestation upstream.

Finally, there is the potential for protection of infrastructure. This has the potential to be a high regret option, e.g. when infrastructure is built in the short-term that is over-designed to uncertain future risks (because of the up-front high capital cost) or where it is under-designed in relation to future events that occur (leading to major damages). River dikes and hard infrastructure can also shift vulnerability, e.g. protecting those upstream, but increasing flows and damages downstream. Balancing all these issues is challenging. A key focus in recent years has been the potential for flexible design (which allows subsequent low cost upgrade later), but also a much greater focus on managed river protection (e.g. Room for the River programmes in the Netherlands), the use of enhanced ecosystem based flood management, etc. These options take considerable time and planning to develop, as well as integrated land-use planning, and early work to start to analyse options and develop the institutional basis for these is a priority.

Across all three areas, the priority is to build up iterative plans. These need to:

- Identify the major risks of concern, which would materially affect Nepal's development plans, growth, people or natural resources, either from the exacerbation of current risks from climate change, or new risks that will emerge. This chapter has identified many of these priority risks.
- Build up possible future scenarios for these risks, developing narratives that start with current climate variability and build on the projections of future climate change and socio-economic trends, and the available impacts information, to look at how these risks could evolve over time. These include scenarios of both the lower and upper end of risks (again as outlined in this chapter). It is also important to identify if there are any potential thresholds that could be significant, e.g. temperature thresholds that trigger risks or go beyond current coping capacity, and to look for suitable indicators to measure and assess these risks.

- To identify portfolios of responses that can address these emerging risks, working backwards to look at the timing of options to ensure the right decisions are taken at the right time. Additional options can be brought forward - or delayed to a later time period - depending on the emerging level of climate change and capacity for implementation. Critically this recognises that actions might be needed now (in the short-term) to enable adaptation to occur effectively in the future, i.e. to make sure the information is available and future options are kept open. It also includes medium and long-term options that may be needed depending on how climate change evolves.

An example is shown for agriculture below.

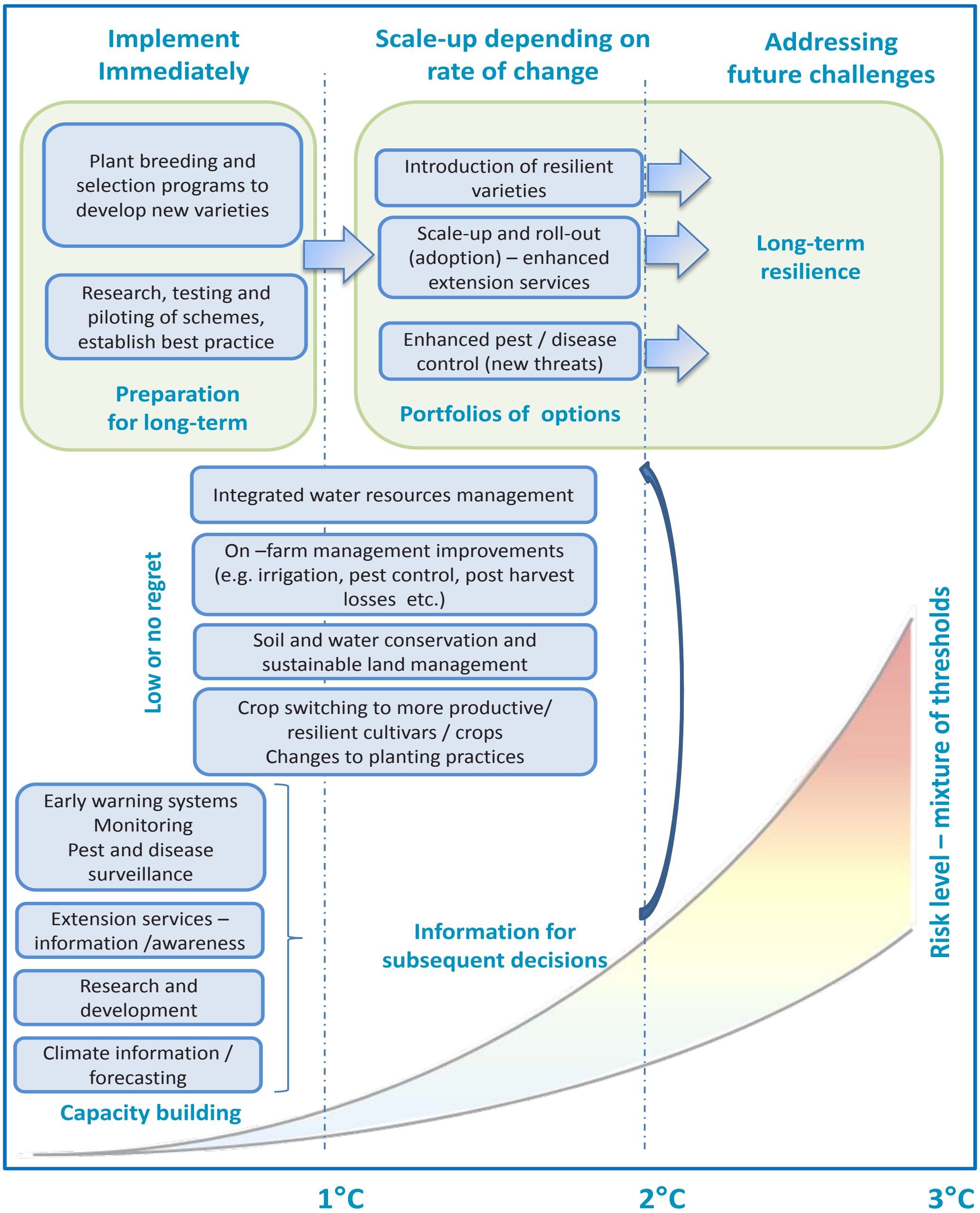


Figure 8.5. An example of an indicative adaptation pathway for agriculture

Source: Watkiss, 2013.

Across all three areas, the priority is to build up such iterative plans to address these longer-term risks. This involves building on the results of this report, in terms of the major risks and uncertainty, and extending to consider potential indicators to monitor, and identify if there are any major thresholds (e.g. temperature tolerance levels that would trigger more significant impacts). A set of options can then be identified across the iterative pathway, noting this will include many early options to provide the information base for later decisions, as well as medium and long-term options that may be needed depending on how climate change evolves. Following these plans, a priority is to start early programmes for critical early steps.

9 Next Steps and Research Priorities

Key Summary Points:

- A number of priority areas for future consideration and research are set out in the report.
- In terms of research, there are priorities around further work to understand climate uncertainty, the indirect economic costs of these impacts, and early research priorities to address long-term challenges.
- In terms of the linkages to policy, the most important priorities are to scale-up existing resilience, to move towards sector adaptation investment plans (aligned to iterative pathways), and to start early programmes for critical early steps.
- To support all of these areas, there is an urgent need to build capacity, with information and awareness raising, monitoring, research, and institutional strengthening.

A number of research and policy gaps - and thus future research priorities - emerge from this study.

A key issue identified is climate projection uncertainty. Ideally, a larger ensemble of downscaled models would have been used, but there were issues on the comparability of models, the level of bias correction, and whether daily data was available, etc. This highlights a priority for any future regional climate model and downscaled runs for Nepal (especially for mountainous regions). There is a need to consider harmonisation procedures and the use of the model outputs in subsequent impact studies. This requires continuous time slices and daily data (with bias correction). It is also stressed that there is a need for multi scenario and multi-model analysis so as to capture the range of climate futures.

There is also a need for improved systematic collection of relevant hydro-meteorological data with different hydro-climatological conditions better represented in national hydrometric networks (e.g. more monitoring); and more research and modelling assessment of hydrological projections with climate change across different catchments with multi-model data.

In relation to impacts, a number of particularly important aspects are highlighted below.

- For agriculture, there is a need to include current and planned irrigation in the modelling analysis, as well as analysis of extremes, impacts on livestock, and potential changes in pests and diseases.
- For hydro-electricity, more hydrological model runs are needed to understand changes in dry season flows for different catchments, to incorporate the potential influence of glacial melt, and to model potential GLOF risks. There is also a need to understand the impacts of climate change on demand (e.g. in terms of additional cooling demand), which is considered a major omission in the current demand projections.

- For water-induced disasters, a clear priority is for a better understanding of the indirect and macro-economic costs of current climate variability and extremes. There is some work progressing on this in Nepal, but a combination of modelling (I-O and CGE) and ex post analysis of major events would be useful.
- Cutting across all of these is a need for enhanced hydrological modelling (on a catchment basis) and overall integrated water modelling (looking at future demand and as well as water management across the sectors).

In terms of the linkage to next steps and particularly adaptation, there is a priority to undertake a detailed mapping of existing adaptation and resilience building activities across Government programmes and other activities (DP, NGO and private) and to i) identify key gaps and priorities ii) assess the activities and actions that need strengthening (including the need to scale-up to address emerging climate change) and iii) to build up mainstreaming priorities as part of sector adaptation investment plans (noting this follows the process in the National Adaptation Plan framework). Similar activities have been undertaken in other countries. It is highlighted that these plans should be built around the iterative plans identified here, due to the high uncertainty involved. Across the three linked areas, this is likely to involve

- Early priority for addressing current climate variability, built around scaling-up existing good practice, enhanced techniques, and supporting capacity building and creating the necessary enabling environment to overcome barriers.
- Advancing mainstreaming through detailed sector adaptation investment plans, with analysis of the options, programmatic activities and costs.
- To build more detailed costed iterative plans for addressing long-term risks, and to start early programmes for critical early steps.
- Consideration of the differentiated impact of climate change while designing adaptation plans and programmes.

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Appendix 1: Stakeholders consulted in the Study

Name	Organization
Arjun Kumar Thapa	MoSTE
Sujan Subedi	MoSTE
Divas Basnet	NDRI
Ram Manohar Shrestha	AIT
Alok Sharma	NARC
Stephanie Borsboom	World Bank
Apar Paudyal	Practical Action Consulting
Dinesh Chandra Devkota	IDS Nepal
Prakash Mathema	MoSTE
Raju Laudari	AEPC
Rudra Bahadur Raya	CECI
Adarsha P. Pokhrel	ADAPT Nepal
Prabha Pokhrel	IDS Nepal
Prakash Koirala	IDS Nepal
Michelle Slaney	PAC Nepal
Govind Nepal	IDS Nepal
Ram Chandra Khanal	CDKN
Paul Watkiss	GCAP
Lipy Adhikari	IDS Nepal
Batu Uprety	Member Climate Change Council
Rajendra Khanal	IUCN
Morten Jespeton	Danish Embassy
Anupa Pant	IFC
Kalpana Pradhan	DRILP-AF
Balaram Mayalu	IDS Nepal
Madan Koirala	CCC-M
Sundar Subedi	MoSTE
Gokarna Mani Duwadee	MoSTE
Dayanand Mandal	NARI
Bimala Devkota	NAST
Prof. Dr. P.C. Adhikari	NAST
Dr. Madhav Karki	Climate Change Council
Manoj Neupane	Practical Action Consulting
Kala Nidhi Pathak	MUAN
Bharati Pathak	Ashmita/ FECOFUN

Laxmi Bhatta	ICIMOD
Subodh Sharma	KU
Dipesh Chapagain	CEN
Bishwa Nath Oli	MoF
Ugan Manandhar	WWF
VB Amatya	Practical Action Consulting
Akhanda Sharma	MoSTE
Punya P. Regmi	YSEF
Manjeet Dhakal	Clean Energy Nepal
Kedar Rijal	CDES/TU
Ramesh Sapkota	CDES/TU
Dinanath Bhandari	Practical Action Consulting
Dinesh Bhuju	NAST/CDES TU
Sagar Rimal	MoFSC
Khem Raj Bista	MoFALD
Hem Raj Acharya	MoFSC
Ishowarilal Bishwakarma	PAF
Purusotam Acharya	MoEN
Rupa KC	HIMAWANTI Nepal
Sitaram Ghale	NIC
Rama Ale Magar	HIMAWANTI Nepal
Hari Ghimire	MoSTE
Gajendra Thapa	MUAN
Santosh Nepal	WWF
Shreejana Bhusal	MoSTE
Ujjal Adhikari	Action for Development
Gehendra Gurung	Practical Action Consulting
Ram Pd. Awasthi	DHM
Purushotam Ghimire	NPC
Resham Dangi	REDD
Hari Prasad Panta	MOSTE
Kathleen Mclaughlin	ICEM
Sunil K Regmi	Hariyo Ban
Dhiraj Pokhrel	Leaders Nepal
Iswor Pd. Khanal	NAST
Ghana Shyam Malla	NARC
Ciranjivi Regmi	NAST
Sundar P Sharma	DWIDP
Kalu Ram Tamang	MUAN
Ramu Subedi	MSFP

Raj Babu Shrestha	PAF
Prem Bdr. Thapa	PAC Nepal
Bed Mani Dahal	KU
Deependra Khadka	Nepal FM
Apsara Chapagain	FECOFUN
Keshab Man Shakya	MoSTE
Keshab Bhattarai	MoSTE
Elizabeth Colebourn	CDKN
Yuba Raj Bhusal	NPC
Subash Ghimire	IDS Nepal
Shankar Pd. Adhikari	MoSTE
Chandra Khadka	Digital Vision
Sadhuram Khatri	IDS Nepal
Shanti Karayat	UNDP
Jagat Lama	ADAPT Nepal
Chet Bahadur Ram	Nest
Chandra Pd. Khanal	NAS
Gyanendra Maharjan	NPC
Shom Shrestha	NPC
Nidarshan Nepal	IDS Nepal
Nitesh Shrestha	ADAPT Nepal
Anita Koirala	MoF
Jit Ram Lama	NGO Federation
Nita Pokhrel	NPC
Dr. Namarata Singh	MoAD
Moti Bahadur Kunwar	MoEng
Basistha R. Adhikari	DWIDP
Manahari Khadka	NPC
RS Khanal	IDS Nepal
Arjun Rijal	CCC
Moushami Shrestha	PAC Nepal
Posh Raj Pandey	SAWTEE
Hari Prashad Pandey	MoF
NC Shrestha	DWIDP
Nabin Kumar Pokhrel	IDS/MSFP
Bhupendra Das	IDS Nepal
Tara Nidhi Bhattarai	IDS Nepal
Govinda Gajurel	Free Lancer
Krishna Gyawali	MoEnv
Uddhav Baskota	MoEnv

Madhukar Uppadhya	NPC
Ashok Regmi	Digital Vision
Kamal Devkota	IDS Nepal
Bhupal Khadka	IDS Nepal
Balaram Poudel	IDS Nepal
Shanti Shrestha	ICIMOD
Jeebachh Yadav	ICEM+METCON
Giridhar Mishra	Dept. of Education
Gopal Babu Bhattarai	NEA
Devendra Adhikari	IT
Sujit Karmacharya	IDS Nepal
Mahendra B. Gurung	NEA
Sanjeeb Baral	MoEN
Dipak Magar	IDS Nepal
Nishant Sharma	IDS Nepal
Sunita Bhattarai	IDS Nepal
Dr. Bhaskar Singh Karky	ICIMOD
Dr. Chakra B. Khadka	Patan College
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Er. Laxman B. Rayamajhi	MWSSDB
Anil Shrestha	IDS Nepal
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Subash Chandra Devkota	NFA
Ms. EMMA Karki	ISET
Rishi Ram Sharma	DHM
Saraju K. Baidhya	DHM
Ran Babu Dahal	D.H.M.
Hem Raj Regmi	MoAD
Krishma P. Pant	MoAD
Arjun K Thapa	MoEST
Bhakta Karki	RRN
Moushumi Shrestha	PAC
G. Malla	NARC
Punya P Regmi	TU
Chiranjivi Regmi	NAST

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Global Climate Adaptation Partnership

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