Building Knowledge for Climate Resilience in Nepal

Research Briefs

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MESSAGE FROM VICE CHANCELLOR

Climate change and its impact has been a major environmental concern worldwide today. Generating field-based empirical data and information is perhaps the first step to help build climate-resilient communities towards achieving sustainable development goals of a country. The Government of Nepal is undertaking various projects on climate change with a goal of minimizing its negative impacts. One such effort is Mainstreaming Climate Change Risk Management in Development, which is one of the five components of Nepal's Pilot Programme for Climate Resilience (PPCR), implemented with financial support from the Asian Development Bank (ADB). I am pleased to record that Nepal Academy of Science and Technology (NAST) has been entrusted to take up a research grant programme to develop knowledge and management tools for climate change.

Since its establishment, NAST has actively been involved in conducting, as well as supporting, scientific research covering various sectors of science and technology of national priorities, including climate change and environment. NAST has also established a national platform of climate knowledge, the Nepal Climate Change Knowledge Management Centre (NCCKMC) as a part of NAPA (National Adaptation Programme of Action). The Climate Change Research Grant Programme (CCRGP) under PPCR is an extension of our efforts to strengthen knowledge base in climate change in Nepal. We are thankful to GoN for giving this opportunity. Nepal's contribution to global warming is negligible in amount; however, it is not spared from the impending impacts of climate change. Paradoxically, for the lack of empirical data, its Himalayas are termed as a 'white spot'. The research studies carried out under various research grants of NAST, including CCRGP, are an attempt towards fulfilling this gap.

We thank all the researchers who, despite hardships following the earthquake April 2015, completed their studies and submitted research reports. The academic inputs by reviewers and mentors to the research work are highly acknowledged with thanks. We are pleased to bring out this compilation of research briefs for wider dissemination.

Prof. Dr Jiba Raj Pokharel
Vice-Chancellor
Nepal Academy of Science and Technology

October 2016

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LIST OF ABBREVIATIONS

AAPA	: Aquatic Animal Protection Act
AAS	: Atomic Absorption Spectrophotometer
ADB	: Asian Development Bank
AEC	: Aquatic Ecology Centre
AEPC	: Alternative Energy Promotion Centre
AFS	: Attributable Fractions
AHP	: Analytical Hierarchy Process
asl	: Above Sea Level
BAP	: Benozyl aminopurine
BGHP	: Budhi Gandaki Hydropower Project
BGRB	: Budhi Gandaki River Basin
BRTS	: Bus Rapid Transit System
C	: Carbon
CO_2	: Carbon dioxide
CAMUM	: Climate Change Impact and Adaptation Measures in Upper Mustang
CBD	: Convention on Biological Diversity
CBM	: Cost Benefit Method
CBS	: Central Bureau of Statistics
CCA	: Climate Change Adaptation
CCRGP	: Climate Change Research Grant Programme
CFUGs	: Community Forest User Groups
CHAL	: Chitwan Annapurna Landscape
CID	: Climate Induced Disaster
CM	: Centimetre
CPUE	: Catch Per Unit Effort
CVM	: Contingent Valuation Method
DAD	: Diode Array Detector
DBH	: Diameter at Breast Height
DFID	: Department for International Development, UK
DHM	: Department of Hydrology and Meteorology
DLS	: Department of Livestock Services

DLSO	: District Livestock Service Office
DO	: Dissolved Oxygen
DoHS	: Department of Health Services
EBD	: Environmental Burden of Diseases
EB	: Energy Balance and Mass Balance Models
FGD	: Focus Group Discussion
FMD	: Foot and Mouth Disease
GCM	: Global Circulation Model
GDP	: Gross Domestic Product
Gg	: Gigagram
GHG	: Greenhouse Gases
GIS	: Geographical Information System
GLOF	: Glacial Lake Outburst Flood
GnPR	: Green Point Ratio
GoN	: Government of Nepal
GPS	: Global Positioning System
GW	: Green Weight
HFHI	: High Frequency High Intensity
HFLI	: High Frequency Low Intensity
HFMI	: High Frequency Medium Intensity
HIS	: Hydrological Information System
HPLC	: High Performance Liquity Chromatography
HS:	: Haemorrhagic Septicemia
IAPS	: Invasive Alien Plant Species
IAs	: Invasive Alien Species
IEC	: Information Education Communication
INGOs	: International Non-governmental Organizations
IPCC	: Intergovermental Panel on Climate Change
IUCN	: International Union for Conservation of Nature (The World Conservation Union)
KCA	: Kanchanjungha Conservation Area
kg	: Kilogram
KII	: Key Informant Interview
KTM	: Kathmandu
LAPA	: Local Adaptation Plan for Action
LCH	: Life Cycle Hypothesis
LDRMP	: Local Disaster Risk Management Plan
LGP	: Liquefied Petroleum Gas
LNP	: Langtang National Park
LRMP	: Land Resource Mapping Project
LSP	: Local Resource Persons
LU	: Land Use

MCA	: Manaslu Conservation Area
MCCRMD	: Mainstreaming Climate Change Risk Management in Development
mm	: millimetre
MoAD	: Ministry of Agricultural Development
MoE	: Ministry of Energy
MoFALD	: Ministry of Federal Affairs and Local Development
MoFSC	: Ministry of Forests and Soil Conservation
MoPE	: Ministry of Population and Environment
Mw	: Mega watt
NAP	: National Agriculture Policy
NAPA	: National Adaptation Programme of Action
NARC	: Nepal Agricultural Research Council
NASA	: National Aeronautics and Space Administration
NAST	: Nepal Academy of Science and Technology
NCAR	: National Centre for Atmospheric Research
NCEP	: National Centre for Environmental Protection
NDVI	: Normalized Difference Vegetation Index
NDWQS	: National Drinking Water Quality Standard
NELD	: Non-economic Loss and Damage
NGOs	: Non-governmental Organizations
NSET	: National Society for Earthquake Technology
PFM	: Project Financing Method
PLA	: Participatory Learning and Action
PPCR	: Pilot Programme for Climate Resilience
PROR	: Peak Run-off Rivers
RCP	: Representative Carbon Pathways
RIO	: Relative Occurrence Index
RoR	: Run-off Rivers
RS	: Remote Sensing
SALT	: Sloping Agriculture Land Technology
SDAN	: Sustainable Development Agenda for Nepal
SDSM	: Statistical Down Scaling Model
SMI	: Soil Moisture Index
SNC	: Second National Communication
SOC	: Soil Organic Carbon
SPCR	: Strategic Programme for Climate Resilience
SPNP	: Shey Phoksundo National Park
SPSS	: Statistical Package for Social Science
STIDH	: Shukraraj Tropical and Infectious Disease Hospital
TDVI	: Total Difference Vegetation Index
TLC	: Thin Layer Chromatography

UNEP	: United Nations Environment Programme
UNFCCC	: United Nations Framework Convention on Climate Change
UTMS	: Urban Transport Model System
VDC	: Village Development Committee
WECS	: Water and Energy Commission Secretariat
WHO	: World Health Organization
WIS	: Water Information System

INTRODUCTION

The Nepal Academy of Science and Technology (NAST), under the technical assistance of the Mainstreaming Climate Change Risk Management in Development (MCCRMD) project—which is part of Nepal's Pilot Programme for Climate Resilience (PPCR), has implemented the Climate Change Research Grant Programme (CCRGP). The MCCRMD project is assisting the Government of Nepal (GoN) to safeguard its development programmes and infrastructures from the impacts of climate change. The project is executed by the Ministry of Population and Environment (MoPE) and administered by the Asian Development Bank (ADB), with financing from the Climate Investment Funds.

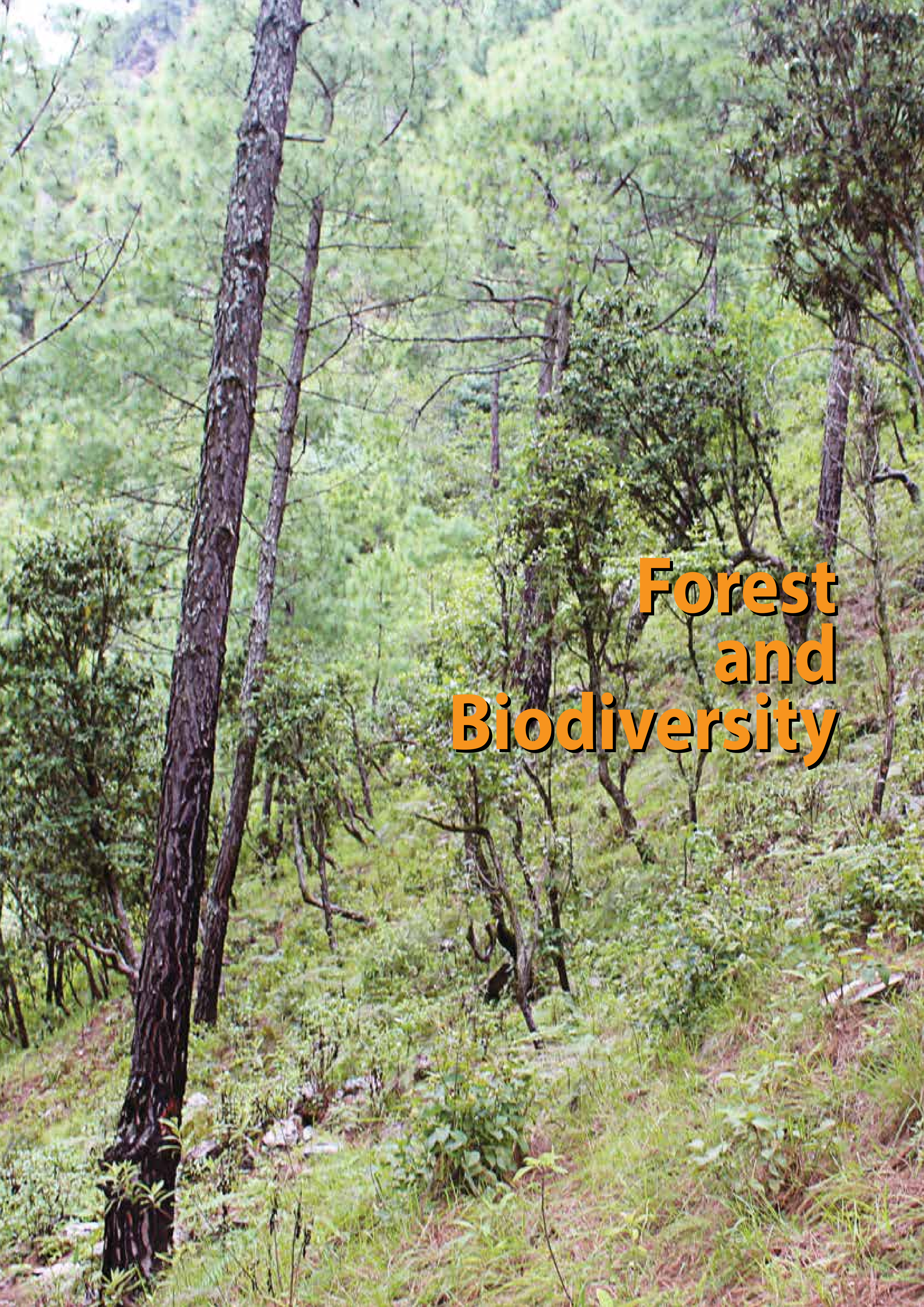
The objective of the CCRGP was to contribute to evidence-based climate change policy in Nepal by providing national researchers with grants to study critical climate change issues. NAST opened a competitive process to Nepali researchers from universities, research institutes, not-for-profit organizations and other entities in order to select high quality research proposals. Thematic experts reviewed the research proposals and the Research Grant Selection Committee, comprising NAST academicians and research scientists, as well as a representative from MoPE, did the final evaluation. The Project Steering Committee, chaired by the NAST Vice-Chancellor and with representation from NAST academicians, MoPE and ADB, provided oversight and endorsed the selection process.

From 413 submissions, 36 research proposals that proposed rigorous methodologies to study substantive climate change issues critical to Nepal's development were selected. Among the selected proposals, 10 were on the theme Forest and Biodiversity, eight on Agriculture and Food Security, eight on Water Resources and Energy, five on Climate Induced Disasters, three on Public Health and two on Urban Settlement and Infrastructure. These research proposals covered fieldwork across 44 districts out of 75 in Nepal. Among the selected grantees, 10 research projects were conducted by experts engaged in non-governmental organizations (NGOs), three from private sector institutions, and the remaining 23 from universities.

This compendium summarizes the findings of the completed research projects. It provides recommendations on policy and future research for government, development practitioners and other researchers in order to contribute to advancing Nepal's knowledge base and policies on climate change. The CCRGP also encouraged researchers to contribute to climate change science at the global level by publishing their findings in reputed international journals.

This compendium of research briefs, along with recommmendations is based on the research project, which will help understand the impacts of climate change in Nepal and provide useful inputs into policy decision.

Forest and Biodiversity



ASSESSMENT OF THE EFFECTS OF CLIMATE CHANGE ON THE DISTRIBUTION OF INVASIVE ALIEN PLANT SPECIES IN NEPAL

Mohan Siwakoti[1], Bharat Babu Shrestha[1], Anjana Devkota[1], Uttam Babu Shrestha[2], Resham Bahadur Thapaparajuli, Krishna Prasad Sharma[1]

Executive Summary

Biological invasion and climate change, both being important components of global environmental changes, are operating synergistically in many parts of the world, threatening biodiversity and people's livelihoods. The problem is severe, particularly in developing countries, which do not have adequate resources and expertise for proper adaptation and mitigation. While the issue of climate change has been well-covered in policy documents of Nepal, biological invasion has receive low priority. Due to inadequate and ineffective management response to biological invasion, a number of invasive alien species and the ecosystems invaded by them have increasingly been threatening the already imperiled biodiversity and livelihoods of farming communities. One of the major impediments to invasive species management in Nepal is knowledge gap. To this end, we have analysed the distribution patterns of invasive alien plant species (IAPS) across diverse physiographic regions, vegetation types and elevation gradient, alone with species distribution modelling under current and future climate change scenarios. Based on this research, we have made four policy recommendations, which are: 1) formulating a national strategy for management of invasive alien species, 2) focusing management on priority invasive alien species based on their current and potential impacts, and priority ecosystems based on the value of biodiversity conservation and ecosystem services, 3) inclusion of invasive alien species management in the operational plans of community forests, and 4) inclusion of biological invasion in the climate change adaptation and mitigation strategies. Immediate policy and management responses are needed to minimize the impact of IAPS in the invaded area and prevent their spread into non-invaded areas.

1 Central Department of Botany, Tribhuvan University
2 University of Southern Queensland, Australia
3 Central Department of Economics, Tribhuvan University

Context and Importance

Biological invasion exacerbates poverty and threatens development through its impact on agriculture, forestry, fisheries and natural systems, which are important bases of peoples livelihoods in developing countries like Nepal. It is considered the second major cause of biodiversity loss, next to habitat degradation. The introduction, or colonization of IAPS, mostly of neo-tropical origin, is one of the most serious threats to different ecosystems of Nepal, particularly those in low and midlands with tropical to subtropical climate. The impacts of IAPS are being experienced equally in both protected areas and outside landscapes. This problem of IAPS is aggravated by climate change, pollution, habitat loss and human-induced disturbances. As the current climate and vegetation belts in Nepal have been predicted to shift upwards under future climate change scenarios, additional areas may be opened for IAPS of neo-tropical origin. Meta analyses and ecological modelling have shown that climate change alters biological invasion by establishing new invasive alien species, changing the distribution of existing species, and modifying the effectiveness of control measures. Climate change and biological invasion interact, producing a multitude of effects that are more severe than their individual impacts combined. Nepal has over 25 species of IAPS and about 219 naturalized plant species. While the number and abundance of IAPS have been increasing over the years, their spatial distribution pattern and impacts on the ecosystem, biodiversity and economy are less known. Neither do we know how the future climate change will affect the distribution of IAPS. As party to the Convention on Biological Diversity (CBD), Nepal has to implement several programmes to meet Aichi Biodiversity Target 9 by 2020, but progress unsatisfactory, primarily due to knowledge gap on invasive alien species. Several reviews have concluded that the current knowledge and capability in this area are inadequate, rendering management responses either ineffective or inefficient.

Research Findings

Twenty-three IAPS out of twenty-five reported from Nepal are found in the Chitwan-Annapurna Landscape (CHAL) and the surrounding areas in Central Nepal. Four of the species reported from the study area, viz Siam weed, lantana, mile-a-minute weed and water hyacinth, are among the thirty-six IAPS included in the list of 100 of the world's worst invasive species by the International Union for Conservation of Nature (IUCN). Ten IAPS were found in 25% of the locations examined. The IAPS were found in seventeen out of the twenty-four vegetation types sampled: in the Terai (4/4), Siwaliks (4/4), Middle Mountains (6/6) and High Mountains (3/3). The IAPS were absent in all of the seven vegetation types sampled in the High Himalayas.

Species richness of the IAPS was high in grassland, shrubland and riverine forests. These ecosystems are subject to frequent anthropogenic (eg grazing, fire) and natural disturbances (eg floods), which increase dispersal of seeds and other reproductive units to these ecosystems and make the habitat suitable for the establishment of IAPS. The highest share of IAPS in the total vascular plant species richness was found in the grasslands of the Siwalik region (22%), followed by the grassland of the Terai (14%), riverine forests in the Siwaliks (14%) and shrubland in the Middle Mountains (11%). Richness of IAPS, as well as their share in the richness of the vascular plant species, declined linearly with increasing elevation. These ecosystems in lowland with high number of IAPS need to be prioritized for ecosystem-based management to reduce their impact, as well as protect the surrounding ecosystems from being invaded by the IAPS.

The upper elevation limit of the distribution of four IAPS (eg crofton weed, blue billygoat weed, spiny pigweed and hairy begger-tick) was higher by 800m than reported in the previous reports. For example, the upper elevation limit of crofton weed in Nepal was reported as 2,400m above sea level (masl) in 2005, but the plant was recorded up to 3,280 masl in the present study. Infrastructure development (eg road construction) and ongoing climate warming might have facilitated upward shifting of these plants. Species like blue billygoat weed, parthenium weed, lantana and bushmint were widespread in the landscape with several isolated 'satellite' populations far from the main population. Presence of isolated satellite population indicates that these species are still spreading to new regions. Mile-a-minute weed was mainly concentrated in the central part of the Siwalik region, but it is expanding westwards and northwards through the establishment of several satellite populations. Among the wetland IAPS, water hyacinth has heavily invaded both the Ramsar sites in the study area.

The species distribution modelling indicated its presence in the highly suitable regions beyond the current distribution of some IAPS. Suitable habitats have also been predicted to change in the future with climate change, but the pattern was not uniform. The suitable habitat is likely to decline for crofton weed, while it is likely to increase for lantana and parthenium weed, both being noxious and globally significant. Therefore, climate change is likely to increase vulnerable areas to noxious and globally significant invasive alien species in the study area.

The species prioritized by communities for management based on their negative impacts in forest are siam weed, mile-a-minute and lantana in the Terai and Siwalik regions, while in the Middle Mountains they are crofton and siam weeds. In agro-ecosystems, blue billygoat weed was the most prioritized species for management from the Terai to Middle Mountains, while in residential areas it was parthenium weed. The blue billygoat weed was not reported as problematic in the 2005 assessment, but it was ranked the most problematic in the agro-ecosystem by two-thirds of the focus group discussions (FGDs) during this study.

Methods

This research is mainly based on primary data generated by extensive field work, but some secondary data (eg herbarium records, bioclimatic variables) was also used to supplement the primary data on species distribution and for the species distribution modelling. Vegetation along the road networks and major trails from the Terai to High Mountains was examined at an interval of 2-10 km (wide interval in the plains and narrow in the mountains) to record distribution of invasive alien plant species. Vegetation sampling was done at twelve locations, covering twenty-four vegetation types and all physiographic regions (Terai to High Himalayas) from approximately 100 to 3,500 masl. We sampled 110 plots of 50m x 20m area following the modified Whittaker nested vegetation sampling method (Stohlgren, *et al.*, 1995). In each plot all vascular plants (pteridophytes, gymnosperms and angiosperms) were enumerated and later categorized into native, naturalized (alien species established in wild and capable of producing offspring without human intervention) and invasive (subset of naturalized species having potential to spread rapidly with negative impacts on the environment and economy). We used the most recently updated list of naturalized (219) and invasive alien plant (IAPS, 25) species for this categorization. We organized altogether thirty-one FGDs near the vegetation sampling locations involving 105 male and 102 female participants (age: 46±11 years). In each FGD, 4–12 participants, mostly executive members of the community forest users' groups (CFUGs), were invited to discuss invasive alien plant species and prioritize them for management. Plant specimens and colour photographs were used to familiarize the participants with the target plant species.

Geographic coordinates were used to produce distribution maps for twenty-two IAPS in the study area. A widely-used ecological niche modelling programme, MaxENT (Phillips, *et al.,* 2006), was used to project suitable habitats under the current climate and future climate change scenarios. Bioclimatic variables from gridded database (approximately 1 km spatial resolution) was obtained from publicly available resources (www.worldclim.com). To model future climate change scenarios, we selected five Global Circulation Models (GCMs) from the available 24 GCMs used in the latest IPCC fifth assessment report 5 (AR5). After selection of GCMs, we modelled distribution of invasive species in four future GHG (greenhouse gas) concentration trajectories, also known as representative carbon pathways (RCP 2.6, RCP 4.5, RCP 6.0 and RCP 8.5), for three different time periods (2030, 2050 and 2070). We downloaded global datasets of future climate from the International Center for Tropical Agriculture (www.ccafs-climate.org), a global agricultural research institution, and extract data for Nepal.

Recommendations

1. Prepare a national strategy for invasive species management: To meet the goal of biodiversity conservation and to comply with the CBD, the GoN has continuously expressed commitments at international forums (eg fourth and fifth national reports submitted to the CBD in 2009 and 2014 respectively) to initiate management of IAS, but it has never materialized due to lack of a national strategy. Biological invasion has been identified as one of the major causes of biodiversity loss in Nepal's National Biodiversity Strategy and Action Plan 2014 and several activities have been planned to meet Aichi Biodiversity Target 9 by 2020. In the absence of a separate strategy, however, management of IAS has received low national priority. This has allowed IAS to spread unchallenged into new regions, threatening biodiversity and people's livelihoods. Efforts made to manage IAS at local level have remained sporadic due to lack of coordination and continuous support. The combined effect of these lacunas is that the IAS continues to expand into new regions claiming additional habitats and ecosystems. Therefore, preparation of a national strategy by an expert panel and its immediate implementation are vital steps for meeting the overall goal of biodiversity conservation.

2. Focus the management on priority species and ecosystems: All IAS are not equally damaging and all ecosystems are not equally vulnerable to biological invasion. Furthermore, available public funding is not adequate to control all IAS. Therefore, available resources and expertise need to be channelized for the management of prioritized species and ecosystems so that the process will be cost-effective and result-oriented. The species enlisted in 100 of the world's worst IAS, having capacity to spread rapidly, invading ecosystems having high conservation and ecosystem service values (eg Ramsar sites, habitats of endangered mammals), and those having direct significant impact on agriculture production can be prioritized for management. For the study landscape, the priority species for management are blue billygoat, siam, mile-a-minute, lantana, crofton weed parthenium weeds in terrestrial ecosystem and water hyacinth and alligator weed in wetlands. Ecosystems having high accumulation of IAS need to be first targeted for management because these species growing in such habitats serve as sources of seeds and other reproductive units for further invasion into surrounding habitats. Therefore, the ecosystems prioritized for management of IAS in the study landscape are grassland, shrubland and riverine forests.

3. Include management of invasive alien species in the operational plans of community forests: Farming communities, including executive members of CFUGs, are not aware of the process (eg origin of IAS, dispersal mechanisms) and management (eg biological control, dispersal pathway) related to biological invasion. They have, however, noticed reduction in provisioning services of forests (eg supply of fodder and non-timber forest products), reduction in farm production, and increased labour input due to IAS. To make communities aware of biological invasion and initiate participatory management of IAS, this issue needs to be included in the operational plan of community forests which is the guiding document for community forest management.

4. Include biological invasion in the climate change adaptation and mitigation strategy: Climate change and biological invasion are important components of human induced global environmental changes, and they are synergistically affecting the environment and biodiversity. In the study landscape, climate change is likely to increase the areas vulnerable to biological invasion at least for a few noxious and globally significant IAS. That means the IAS, facilitated by climate change and other anthropogenic activities (eg transport of agriculture produce), is likely to spread from the lowlands to the mountain region at higher rate and to higher elevation. Those mountain communities who are vulnerable to the direct impact of climate change will have to face additional problems due to biological invasion. Therefore, potential damage due to biological invasion needs to be integrated into the climate change adaptation and mitigation strategies. If mountain communities are made aware of the potential IAS that are already problematic in lowlands, their early detection and eradication would be possible, which is the most cost effective way of IAS management.

Future Research

Undertake periodic assessments of invasive alien species: Periodic assessments of IAS at landscape and national levels will help to identify new IAS, highly impacted ecosystems and the regions vulnerable to biological invasion. Information generated by such assessments will help to update the list of IAS, prioritize species and ecosystems for management, and revise national strategies on IAS and biodiversity conservation.

Identify dispersal pathways of invasive alien species: Within the introduced range, invasive alien species dispersed by natural means, as well as by human activities such as intentional introduction, vehicle movement, transport of agriculture produce and construction materials, etc. Some infrastructures such as roads, irrigation canals, power transmission lines, etc serve as dispersal corridors for invasive alien species. Identification of the dispersal process and pathway of each species will help to device a strategy to minimize the dispersal rate, if not prevent dispersal.

Conclusion

Twenty-three out of twenty-five IAPS of Nepal were found in the Chitwan–Annapurna Landscape and the surrounding areas. There was high concentration of IAPS in lowlands, and their number, as well as share in vascular plant species richness, declined with increasing elevation. The ecosystems and habitats under invasion by various IAPS have been increasing rapidly and many of the IAPS were recorded from significantly higher elevation than a decade back. The species prioritized by communities for management in forest and other natural vegetations based on their negative impacts are siam weed, mile-a-minute and lantana in the Terai and the Siwalik regions, and crofton weed and siam weed in Middle Mountains. In agro-ecosystems, blue billygoat weed was the most prioritized species for management from the Terai to Middle Mountains, while in residential areas it was parthenium weed. The species distribution modelling showed that there are still highly suitable regions beyond the current distribution of some IAPS. Suitable habitats of some noxious and globally significant IAPS have also been predicted to increase with future climate change in the study area. Immediate policy and management responses are needed to minimize the impact of IAPS in the invaded areas and prevent their spread into non-invaded areas.

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REGENERATION AND DISTRIBUTION MODELLING OF *Larix* species UNDER CLIMATE CHANGE SCENARIOS IN NEPAL HIMALAYA

Prakash Chandra Aryal[1], Man Kumar Dhamala[1], Madan Krishna Suwal[2]

Executive Summary

As climate change has contributed to shifting the species range, especially in sensitive areas like mountains, resource management strategies need to address climate change in decision-making. Based on the hypothesis that Himalayan trees with resource value to local communities should survive, regenerate and contribute to conservation outcomes under climate change scenarios, we measured the regeneration and possible suitable areas for *Larix potaninii* var. *himalaica* and *Larix griffithiana.* Taking *Larix* as a representative species in the upper temperate and subalpine system in Nepal Himalayas, we have predicted future range contractions with significant upward shifts and random patterns.

Equally important, information on recruitment and regeneration of the species showed varied patterns that reflected different levels of stress on the population and its associated ecosystem. Regular monitoring of population and multiple species distribution modelling to predict the fate of associated species and ecosystems are suggested in decision-making, while formulating protected area management and local resource use plans. Conservation authorities and local communities are expected to benefit from the information generated.

Context and Importance

Climate change and its impacts on mountain ecosystems have been hot topics of discussion and policy debate. The impacts have been realized in Nepal at public level through research, mostly in high altitude areas. The impacts on resource security and management are fraught with disruptions in resource availability and supplies. As part of mitigation and adaptation strategies for resource management, plantation and afforestation programmes need to be based on scientific information to ensure that such programmes match with the habitat suitability of the species. This is possible through species distribution modelling under future climatic changes. However, most of the climate change research works on forests in high altitude areas have covered isolated issues like treeline dynamics, alpine vegetation, forest structure, soils and community perceptions, which clearly entail the need for an integrated research approach involving species regeneration, climate sensitivity and response, and future distribution. This study was designed to understand the climate response on tree species *Larix potanini* and *Larix himalaica,* found in isolated areas in the upper temperate and subalpine parts of the Nepal Himalayas, with field information collected from the main valleys of the three protected areas, namely Ghunsa Valley in the Kanchanjungha Conservation Area (KCA), Tsum Valley in the Manaslu Conservation Area (MCA) and Langtang Valley in the Langtang National Park (LNP).

Research Findings

The recruitment dynamics of trees inferred through tree size distribution showed healthy regeneration of species. Sustainable regeneration and growth of *Larix* in combined analysis shows hope for *Larix*. As most of the trees sampled are coppices and all the areas are under pressure from cattle grazing and tree-cutting, the species may not sustain the disturbances. Resource managers need to monitor the tree regeneration and harvest rates to manage a balance in resource extraction from natural forests. Communities in all three sites prefer *Larix* as an important timber species and communities, especially those of Chhekampar of Gorkha, have higher preference for *Larix* as the main timber species. Their preference for the species can

1 Golden Gate International College, Kathmandu
2 University of Bergen, Norway

be detrimental if harvest exceeds regeneration. The Langtang *Larix* trees are scattered in small numbers, and, due to tree-cutting and grazing pressure, tree survival and seedling survival rates are very low. The episodic nature of the regeneration, as reflected by diameter distribution and seedling–sapling status, increases the unpredictability of forest regrowth.

We used 'climate only' predictors to the distribution modelling of *Larix* as this has been a popular approach to species distribution modelling under the data limitation constraint. The predictive power of the model is still high. Accounting for human influence in the models can sometimes generate information valuable to managing the species under climate change, especially when the species is sensitive to change.

The species distribution models show that the *Larix* species have more available potential niche; the biotic resistance, however, could have limited the current distribution. The higher contraction of species range by 2050, followed by some expansion till 2070, yet a net contraction from the current range with climate change, shows complex distribution dynamics. Additionally, the influence of extreme cold conditions and increase in winter precipitation will have more influence on the species distribution. Conservation areas designed to protect biodiversity should consider this as the threatened species and associated ecosystem functions will be greatly altered with increased severity of climatic events.

Through SDM we show only the potential niche and changes therein with climatic influences. All potential niche spaces are, however, not available to species establishment and survival under anthropogenic influences.

Methods

Three methods have been integrated to understand the dynamics of *Larix*: (i) addressing the species recruitment, (ii) climate–growth response through dendro ecology, and (iii) future distribution or habitat suitability using the species distribution modelling. *Larix* surveys using belt transects along altitude whenever possible and alternative 20m x 20m plot surveys in belts, measuring and counting trees, saplings and seedlings were adopted in three study sites.

Tree cores extracted using increment borer were analysed to prepare tree ring chronology. The chronologies were correlated with temperature and precipitation of station data. Climatic reconstructions were carried out for suitable chronology using the transfer function.

The species distribution modelling was employed using presence only data and for climate only variables for three climate scenarios, viz current climate, future climate 2050s and 2070s with RCP4.5 equivalent to B1 emission scenario. The model was set at 5,000 iterations, 20 replications with 20,000 background points and sub-sampling of 30% of presence points for test. The output was obtained in ASCII type in logistic format (prediction range between 0 and 1). The predicted maps were prepared in binary (suitable/not suitable) with 10 percentile training presence logistic threshold from Maxent (Phillips, *et al.,* 2010) and Relative Occurrence Index (RIO). A list of variables with their contributions to model was extracted from the final average summary.

Recommendations

Monitoring of species' demography to observe the responses from anthropogenic disturbances and climatic stress: It is necessary to ensure that the regeneration is sustainable in core population areas. To ensure conservation and adaptation, it is important that the species are able to migrate or shift in range when the population is able to sustain itself under stress, which is possible only when recruitment and regeneration are healthy. With rise in temperature, in the future, the extremes of seedling distribution might shift towards colder temperature than those of mature trees (Monleon and Lintz, 2015). The survival must contend with landscapes fragmented by anthropogenic disturbances (Lazarus and McGill, 2014). Demographic monitoring will be able to show the survival dynamics under anthropogenic and climatic conditions.

Delineation of species areas for conservation to serve as source population and continue natural dynamics: Mountain protected areas under human use and away from the direct sight of management authorities face unsustainable tree felling and grazing pressures in forests. To overcome the regeneration gaps, certain areas with high suitability for species should be set aside for public use to ensure population balance, at least for *Larix potaninii* var *himlaica* in the Langtang Valley under double peril as it is rare, endemic and restricted to a small range (Farjon and Page, 1999). This will contribute to reducing disturbances through local resource alternatives to tree-felling and high grazing pressure to ensure survival through tracking of warming climate and seedling colonization of newly favourable areas (Monleon and Lintz, 2015). The people's right to local resources cannot be curtailed. Alternatives such as planting of useful local species to supplement the *Larix* demands can be adaptive options by reducing the pressure on *Larix*. Alternatives to timber should be found soon as post-earthquake reconstruction of villages, particularly in Langtang and Tsum, will require widespread tree-felling, leading to increased disturbances to forests, which may further reduce the *Larix* population.

Future Research

Demographic studies from possible current distribution areas and regular monitoring will strengthen the evidence of regeneration problems and provide data quality strengths. Current results based on climatic response of tree rings are sufficient to show the temperature and moisture limitations to tree growth. Incorporating robust mathematical models and predictive modelling such as machine learning will help increase confidence by specifying the influence of climatic and anthropogenic factors in tree growth. An analysis involving land use changes relating to current available space may influence the future assemblage and distribution of the species. A multispecies modelling approach, including anthropogenic factors, to understand complex influences in community and ecosystem processes, will boost confidence in information and decision-making process. Biotic stress such as competition should be involved in modelling. For example, Gaire, *et al.* (2014) shows high recruitment of *Abies spectabilies* in Manaslu area, which may limit the regeneration of *Larix* as these are associated species.

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PLANT WATER RELATIONS AND ALTITUDINAL SHIFTS OF *Quercus semecarpifolia* IN RESPONSE TO DROUGHT AND CLIMATE CHANGE IN NEPAL'S HILLS

Kanta Paudyal[1], Anjana Bista[1], Baby Sharma[1], Bipana Acharya[1], Kumidini Shakya[1]

Executive Summary

In order to understand the effects of temperature increase and resulting droughts on *Quercus semecarpifolia,* a Himalayan oak found at altitudes between 2,100 and 3,800 metres, a range of measurements were taken from five sample trees at two sites at Fulchowki Hills, Lalitpur, over 15 months. The measured factors included different indicators of change in phenology—natural changes in the plants that occur as a response to changing environmental conditions, which, in this case, were primarily related to the seasonality and amount of water in the form of rainfall (precipitation), as well as the general increase in the temperature brought about by global warming.

Our research indicated that *Q. semecarpifolia* exhibited significant markers of water-related stress and that it had adopted a number of adaptation measures to cope with these changes. By studying the same plant at different altitudes, we were able to understand that the plant altered its patterns of leaf emergence, colouring, photosynthesis, as well as other physiological attributes, to better adapt to conditions at different elevations. We observed the means by which this species of oak conserved water during dry months and how these changes in physiology were linked to varying temperature and rainfall.

There exist many research efforts that could elaborate our understanding of the adaptations of these plants to the changing environment. There is, however, enough evidence to postulate that, by instituting policy changes at the community, local and regional levels, and by educating the general public better about these plants and their struggles, we can aid in the long-term survival of this and other species of the Himalayan oak.

Context and Importance

Global warming has long-reaching effects across the world. While many of us are familiar with how polar ice caps are being affected by rising temperatures, a change in rainfall patterns has also been observed across the world, leading to substantial regional and seasonal variations amongst forest species. Significant changes in rainfall patterns can lead to excessive periods of drought. Drought is one of the most important, complicated and least understood natural hazards for plants and recuperation from the effects of drought is very difficult because of the mechanisms involved.

The natural vegetation of the central Himalayas grows in difficult environmental conditions. There is concentrated rainfall during the monsoon from mid-June to mid-September, followed by a dry period of eight or nine months, causing profound effects on plant adaptation and ecosystem processes. The role of the environment, particularly drought, however, is poorly understood in the context of the distribution and adaptation of Himalayan tree species. *Q. semecarpifolia,* a high altitude oak, is an evergreen dominant species of the central Himalayan vegetation and is distributed from south-west China to Afghanistan from elevation of 2,100 to 3,800m.

This research was carried out to understand how one of the most important oak species in the northern hemisphere copes with changes in rainfall patterns and droughts. By understanding how this forest species endures the problems brought about by droughts, we can assess the nature and direct impact of our activities and devise potential ways by which we can help this species survive and flourish.

1 Amrit Science College, Tribhuvan University, Kathmandu

Research Findings

A number of different effects on the sampled trees were studied to understand the overall changes brought about by droughts on this species. By comparing the measured values across the two sample sites, coupled with statistical analysis of the differences in values across the different sampled trees, we were able to evaluate whether or not *Q. semecarpifolia* exhibited signals that indicate phenological changes to cope with environment-induced stresses.

Out of the attributes studied, there were a number of differences between the two sites across multiple variables. Since we were primarily looking to see how the plant physiology changed as per variations in the pattern of rainfall throughout the measurement period, we looked at the different indicators in relation to monthly changes. In addition, since the different sampled sites were located at different altitudes, we also used the differences between the sites to account for any exhibited patterns that might be correlated to what is known as altitudinal shift—the movement of plants from one altitude to another.

The Himalayan oaks, due to the existence of the monsoon season, have unique properties when compared to other species of oak across the world. This includes the adaptations they have made to cope with long periods of dry months. At the higher elevation sample site, the amount of dry matter in the leaves was higher, indicating that the trees at the higher altitude had higher amounts of photosynthesis compared to the lower altitude samples. This type of behaviour also brought about the understanding that the trees at the higher altitude are more easily able to convert starch into soluble carbohydrates in order to adjust to a higher level of water-induced stress.

Using another factor of measurement, we were able to determine that the plants at the lower altitude exhibited higher sensitivity towards embolism—the presence of gas bubbles in the plant's vascular system—and exhibited this characteristic sooner than the trees at higher elevations, suggesting that those that grow at higher altitudes have better adaptation to deal with water stresses. Similar patterns were seen in regard to leaf senescence—the phenomenon by which leaves turn colour during dry summer months. Not only did the leaves change their colour at different times based on altitude, but they also changed shape and became spinier in higher elevations to conserve more water.

There were, however, some factors that did not change with altitude. Phenological events such as flowering, bud break and shoot elongation occurred simultaneously at both sites. This indicates that the growth and reproductive systems of these plants are not affected by the seasonal patterns of precipitation. There were some minor differences in behaviour though; at lower elevations, these plants shed their leaves prior to shoot elongation, whereas at higher elevations, shoot expansion occurred before the leaves were shed. This leads us to the finding that increasing water stress at lower elevation increases leaf shedding and delays shoot elongation.

This research was able to provide a better understanding of how these plants adapt to changes in the environment and indicated patterns by which they performed adaptations. These plants have to cope not only with the water stresses brought about by dry summer months, but also with the changing climate conditions. In order to cope with such conditions, especially an increase in temperature and variations in precipitation, these plants have been shown to 'shift' to a higher altitude over time and modify their overall physiology so that they are able to survive despite really difficult conditions.

Methods

The primary research site selected for this study was Fulchowki Hills due to the prevalence of *Q. semecarpifolia* in the forests there. Measurements were made for fifteen months at monthly intervals at two different altitude sites (Site 1: 2,421m and Site 2: 2,643m). Five trees were selected at each site and marked. All the measurements were taken from the same trees throughout the period of this research.

The response of plants to moisture stress was estimated using different parameters of water relations measured in the field and further analysed in the laboratory to explain their distributional differences. Different plants adopt different adaptation strategies to combat the environmental stress. Hence, a variety of measurements were performed to cover their possible adaptive behaviours. The factors measured are as follows:

- Tree Water Potential (Ψ_w) at predawn and midday
- Pressure–Volume Curve Analysis
- Xylem Conductance
- Twig Starch Percentage
- Specific Leaf Mass
- Wood Water Properties
- Phenological Cycles: Leaf Senescence, Leaf Emergence, Flowering, Fruiting, Twig Emergence, etc.

Recommendations

While the research activities that we carried out only focused on one particular species of oak, there are a number of preliminary implications that can be drawn based on our findings. The effects of human activities are definitely 'pushing' these plants to higher elevations to find a better suited climate, as well as access to water. Therefore, there are three major areas where certain policy measures could be taken to alleviate some of the stresses that these plants are enduring:

1. Conservation of Water (Recommendation to Local Community)
2. Encroachment and Deforestation (Recommendation to Local Government)
3. Global Warming (Recommendation to Policymakers)

These plants are very lucky to have vast and expansive root systems, which can get into deep soil and gain access to water. Nevertheless, during summer months, the existence of embolism in the lower elevation plants indicates diminishing amount of groundwater, which is putting enormous stress on these valuable plants. Due to rampant use of groundwater pumping through means such as well aided by electrical and other types of pump for consumption in human-related activities, the overall water table has been found to be decreasing quite significantly, even in the region surrounding the Fulchowki Hills. As groundwater ceases to become accessible, the plants that cannot gain access to water, which is as vital to their physiological processes as it is to all other plants and humans, these plants will simply not be able to survive.

One policy intervention that may aid these plants would be to limit the amount of groundwater that can be pumped for human activities, especially around areas that are already seeing quite a bit of groundwater reduction. By limiting the use of boring wells and other mechanical systems of drawing water out of the ground and using them in household or commercial applications, we will be able to conserve groundwater and help these trees survive longer. Any effort to reduce groundwater use can quickly be monitored through the parameters we have studied, and further measurements can be used to understand overall efficacy.

Another area of policy intervention in our country deals with the direct impacts of human activities on forests and plants such as *Q. semecarpifolia*. Rapid expansion of human settlements into the adjoining regions of forest areas such as those studied in the Fulchowki Hills brings about a number of detrimental effects on the plant species found in such regions. As human settlements grow in such areas, they end up causing both direct damage in the form of clearing of forests for land use and indirect damage in terms of the use of groundwater, as described earlier. By instituting policies that limit the amount of human expansion in such heavily-wooded areas, we will be able to conserve not only the trees that make up the forests but also the animal life that depends on such forests for their survival. Any policy changes that make it more difficult to develop settlements that encroach further into forestland will aid their survival.

Deforestation is another major cause of danger to the survival of these plants. No matter what the reason for felling of these trees, such as lopping and wood harvest for fodder and firewood or forest fires, is, such activities should be considered punishable so that the people who carry out these acts should face some repercussion for doing so. Stronger patrolling and increased liability for deforestation and for damaging forestland could act as strong deterrents to those that currently do not face any punishment for clearing out vast areas of forestland for their own benefit.

A further potential policy change that may turn out to be quite beneficial for the long-term survival of these plants is to control the rate of global warming through effective controls such as carbon-neutral policies. Due to excessive emission of greenhouse gases, global warming has been shown to have a devastating effect on all cold climates. While this is apparent in the case of melting polar ice caps, the ascension of these trees from lower altitudes to higher altitudes suggests that rising temperatures are forcing these plants to move to areas where they can get some relief from temperature-induced stresses. As the overall temperature increases, the rate of transpiration (loss of water through leaves) gets affected, pushing these plants to adopt features that will reduce transpiration to conserve water.

By instituting carbon-neutral and regulated greenhouse gas emission policies in the case of local industries, as well as from a global carbon trade perspective, there is a potential to slow down the overall warming of the earth. If we succeed in lowering the overall rate of temperature increase, we might be able to provide these plants enough time to adapt to the changing conditions via phenological variations. Although it is true that a country like Nepal can have limited impact on the global equation, even if we were able to completely cease greenhouse gas emissions, the fact that we are at the foothills of the tallest mountain range in the world should enable us to not only advocate for right policies to be put in place, but also become a torchbearer to help conserve our national heritage, while aiding species of plants that exist in our unique topography and climate.

Future Research

In order to better comprehend the behaviour of these plants and enable us to help alleviate the struggles faced by *Q. semecarpifolia* and other Himalayan forest species, it is imperative to carry out further research activities of this type. Even during the course of our research, due to the April 2015 earthquake, some of our equipment was damaged and we had to carry out our research and analysis despite being unable to get all of them operational. Also, the intended research timeline, which included 18 months of measurements, was adjusted to meet the project timeline requirements and shortened to fifteen months.

Albeit, the research team feels that there is need for further measurement of variables connected to this research. These plants should be studied further to gather more data around phenological changes exhibited by these plants in response to temperature and water-induced stresses. Future research activities would entail a longer timeline of data gathering, including additional factors not currently measured due to unavailability of equipment, as well as complications brought about by the earthquake of April 2015. Additionally, we would like to increase the scope of this research by studying other species that are found to co-habitat with *Q. semecarpifolia* so that we can understand the effects of climate change on a larger range of Himalayan trees.

Furthermore, similar research should be carried out in other locations around Nepal and the broader Himalayan region. By carrying out additional research activities in a broader region, we will be able to paint an accurate picture of how significantly these forest species are being impacted by climate change.

Conclusion

The effects of climate change on Himalayan oak species provide us with a good look on how human activities can potentially impact our surroundings, as well as the global environment. This research showed a correlation between climate change and movement towards higher altitudes as well as other physiological changes in *Q. semecarpifolia*. This particular species of Himalayan oak has demonstrated a lot of adaptations in order to survival. Not only have there been phenological changes such as changes in the pattern of leaf colouring, size/shape and photosynthesis, research has shown that these plants are continuing to move up to higher altitudes due to environment-related stress. These plants also bear telling signs of their struggle to cope with increase in temperature and change in rainfall patterns. Without concerted efforts to ensure their survival in our forests, we risk the advent of a greater disaster where our forests get thinned out and eventually disappear.

While there is need for additional research to help corroborate the findings of this research effort and shed light on other significant factors, there is still a lot that we can leverage from this effort, which can aid in developing policies that will ensure the survival of our forest resources. By implementing changes at community, local government and regional levels, we may be able to aid these plants through amelioration of conditions and reduction of environment-induced stresses. The study of this particular species has provided with a better understanding of how this plant copes with the changes in the environment brought about by climate change.

IMPACT OF CLIMATE CHANGE ON THE QUALITY OF HERBAL DRUGS: A THREAT TO PLANT-BASED TRADITIONAL KNOWLEDGE FOR LIVELIHOOD

Rajendra Gyawali[1], Bipesh Pyakurel[2], Tirtha Maya Shrestha[1], Jagendra Khadka, Prem Nayaran Paudel[1], Rudra Upreti[1], Nira Paudel[1], Prerak Regmi[1]

Executive Summary

Anthropogenic causes, together with the impact of climate change on biodiversity and environment, increase the risk of extinction of crude drug species used for traditional medication in Nepal. Study of possible effects of climate change on medicinal plants is particularly significant due to its value within the traditional systems of medicine and livelihoods of Himalayan people. Many traditional healers have been practising plant-based healthcare system to earn their livelihoods and to serve the public. As a component of climate change, temperature stress and relative humidity can affect secondary metabolites, which are the basis for their medicinal properties and for curing diseases. Therefore, this study was undertaken to survey the impact of climate change on crude drugs of traditional practice in lower Mustang. To understand the impact of environment, ie temperature and relative humidity, on quality of medicinal plants and their therapeutic properties, we cultivated medicinal plants in different conditions and analysed them.

Herbal resource-based traditional medication practices have been found declining in the lower Mustang area due to climate change. Impact of climate change on medicinal plants in different parameters such as accessibility, yield, efficacy and regeneration was recorded by the questionnaire survey. Impact was seen in the yields of medicinal plants, particularly the production of *Cordyceps sinensis, Berginea ciliate, Swertia mussofi, Lancea tibetica, Pterocephalus hookeri, Aconitum tanguticum, Dactylorhiza hatagirea* and *Fritillaria cirrhosa* has reduced. Due to the indispensable role of *Amchis* in herbal preparations, some of these plants are being cultivated in private lands. The quality of medicinal plants is, however, gradually deteriorating over the period. Some new plant species of subtropical altitude are also appearing at altitudes of 3,000m and above. Temperature stress has been affecting the morphology and chemistry, ie secondary metabolites of the medicinal plants, which are the basis for their medicinal properties. When the plant was cultivated at 5°C higher temperature in greenhouse with average 5% relative humidity difference, the impact was significant. Plants were found taller, with thicker stem in warm conditions, but the leaf size, root size and moisture content were found higher in the plants cultivated in normal environment. Necrosis of leaf on some plants was also observed due to rise in temperature. Similarly, shoot number, root length, stem thickness, etc. were found negatively influenced by high temperature. Increasing the temperature also reduced essential oil production. GC-MS analysis of essential oil showed that *Eucalyptol, Camphor, Alpha-Humulene, Isocaryophyllene* and *Neocembrane* were significantly reduced in the plants grown in high temperature inside the greenhouse. Antimicrobial property of essential oil Artimesia grown in high temperature showed strong inhibition against *Pseudomonas aeruginosa*, but in case of Eupatorium, it was found less. Similarly, anti-inflammatory property of *Artimesia* decreased with increasing temperature, but such effect was not found with Eupatorium. Although climate change impacts chemistry, yield, morphology, etc of medicinal plants, some of the plants collected from Mustang, like *Rhododendron* and *Utrica*, showed that they are still performing well in pharmacological activity, ie antimicrobial and antidiabetic property.

[1] Department of Pharmacy, Kathmandu University
[2] Research Development and Action Nepal

Context and Importance

This project has demonstrated significant variations in the quality of herbal medicines for therapeutic properties and changes in secondary metabolites. This finding has projected possible threats of climate change to medicinal plant resources in Mustang. Change in phytochemical composition and its impact on pharmacological properties due to temperature rise could be an indicator of adaptation measures in traditional medication.

Research Findings

Herbal resource-based traditional medication practices in the lower Mustang area have been found declining due to the impact of climate change. Impact of climate change on medicinal plants in different parameters such as accessibility, yield, efficacy and regeneration has been recorded by the questionnaire survey. Impact was seen in the yields of medicinal plants, particularly production of *Cordyceps sinensis, Berginea ciliate, Swertia mussofi, Lancea tibetica, Pterocephalus hookeri, Aconitum tanguticum, Dactylorhiza hatagirea* and *Fritillaria cirrhosa* has reduced. Due to the indispensable role of *Amchis* in herbal preparation, some of these plants are being cultivated in their own private land. Some new subtropical plant species also appeared at altitudes of 3,000m and above. Temperature stress has been affecting morphology and chemistry, ie secondary metabolites of medicinal plants, which are the basis for their medicinal properties. While they were cultivated at 5°c higher temperature with average 5% relative humidity difference, the impact was significant. Plants were found taller, with thicker stems in warm conditions, but the leaf size, root size and moisture content were found higher in the plants cultivated in lower temperature.

Necrosis of leaf was observed in warmer conditions in some plants. Similarly, shoot number, root length, stem thickness, etc were found negatively influenced by high temperature. Essential oil production also reduced due to increase in temperature. GC-MS analysis of essential oil showed Eucalyptol, Camphor, Alpha-Humulene, Isocaryophyllene, Neocembrane to have significantly reduced in the plants grown in high temperature in greenhouses. Antimicrobial properties of Artimesia grown in high temperature showed that inhibition of *Pseudomonas aeruginosa* was more efficient, but in the case of Eupatorium, it was found reduced. Similarly, anti-inflammatory property of Artimesia decreased with increasing temperature, but it was not found so in Eupatorium. Although climate change did have an impact on the chemistry, yield and morphology of medicinal plants, some of the plants collected from Mustang, like rhododendron and Utrica, still performed well in pharmacological activities, ie antimicrobial and antidiabetic properties.

Methods

The study was conducted in Lete, Marpha, Jomsom, Kagbeni and Muktinath Village Development Committee (VDC) ares in lower Mustang. A field visit was made in November 2015 and June 2016 each. The present study was undertaken in and around the eight villages of Mustang district, viz Lete (2,480m), Tukuche (2,950m), Marpha (2,670m), Jomsom (2,720m), Kagbeni (2,810m), Jharkot (3,270m) and Muktinath (3,300m). The following methods were employed to collect information:

a) ***Direct field observation and questionnaire:*** It was administered on traditional faithhealers, *Amchis* and local key people during a twenty-day stay in lower Mustang.

b) ***Key informant interview:*** Key people (local faithhealers, *Amchis*, Ayurvedic healers and elderly local people, local teachers, etc) were consulted.

c) ***Questionnaire survey:*** Random sampling was applied based on the field situation, and purposive sampling was done for people above 30 years.

d) ***Data analysis:*** The obtained field data were fed into the MS Excel program and analysed quantitatively and qualitatively. Quantitative data were depicted by charts and diagrams, whereas qualitative data were analysed by description and discussion.

e) ***Sample collection:*** Samples of some medicinal plants were collected from Lete VDC.

f) ***Selection of medicinal plant species for greenhouse work:*** Artimesia and Eupatorium were chosen for cultivation in the greenhouse and outside in normal conditions. These plants were selected because they can be harvested within a year, contain essential oils and can easily be analysed by the GC-MS facility.

g) ***Measurement of temperature and relative humidity:*** Relative humidity and temperature within and outside the greenhouse were measured by hygrometer (ZEAL hygrometer, England).

h) ***Climatic data collection (secondary source):*** Climatic data were collected from different publications (original source was the Department of Meteorology), which was used for trend analysis of temperature and precipitation patterns.

i) ***Laboratory work:*** Biological activities of samples *Utrica dioica*, *Rhododendron anthopogon*, *Artimesia spp* and *Eupatorium spp* plants were carried out to assess whether or not these plants were actively working to cure diseases.

j) ***Quality evaluation:*** Chromatograiphic analysis, GC-MS, was used for analysis of essential oils (WHO, 2007; Gyawali, *et al.,* 2012). Apparatus of oil analysis was analysed by the GC/MS system Shimadzu GCMS-QP 2010 at the Department of Plant Resources, Kathmandu.

k) ***Bioactivity:*** Mice of either sex, microorganisms, reagents and enzymes were used to evaluate the effect of crude drugs for anti-diabetic properties by Streptozotocin-induced diabetic animal model, Antimicrobial activity by Disc diffusion method, Cytotoxic test by brine shrimp assay, Analgesic activity by Mouse writhing assay, anti-inflammatory activity by formaldehyde test were followed for the evaluation of crude drugs from higher and normal temperature according to Maria and Rota (2008), Koster (1959), Sayyah, *et al.* (2003), Meyer, *et al.* (1982) and Yen and Duh (1994).

Recommendations

A climate change policy on quality of medicinal plants should have been an outcome of domestic necessity because Nepal, a least developed country, is highly vulnerable to the adverse impacts of climate change. Our findings suggest a significant relationship between chemistry, pharmacology and morphology of medicinal plants and climate change, temperature and relative humidity. Increases in temperature will have effects on the yield, morphology and chemistry of medicinal plants. Once the chemistry of the plant changed, the therapeutic properties also changed. Thus, it is assumed that the therapeutic quality of the medicinal plants of the Himalayas, particularly Mustang, is already being negatively affected by increases in the daily maximum temperature. Climate change is affecting medicinal and aromatic plants around Mustang and could ultimately lead to loss of some key species. Extreme weather events have begun to impact the various medicinal plants in Mustang. Plants have a lot of time-sensitive relationships and many will be disrupted by climate change in the future. Changes in climate are also causing plants to migrate to new ranges. The degradation of natural forest has direct influence on medicinal plants and their growing environment. Therefore, we should take climate change, deforestation and medicinal plant loss collectively. We have already witnessed the impact of climate change on many plants, eg *Yarsagumba*. New international initiatives, such as the pilot programme, and new national policies, such as the action plan to prevent and control over-harvesting of such resources, should be promoted. If policymakers are aware of the local impact of climate change on medicinal plants, then it can be mitigated without missing the opportunities. Crafting a policy for greater sustainability of high altitude medicinal plants in the short and long run requires taking into account the differences between central and peripheral locations.

Four important recommendations emerge from this work.

First, since the rising temperature beyond a critical threshold level seems to have a negative effect on the availability, yield and quality of medicinal plants, future research should focus on the genetics of these plants and their conservation and cultivation in natural habitat. To reduce pressure on forest, cultivation of medicinal plants in their pocket areas, whether private land or government forest, should be promoted as scientific forest management.

Second, the present study could not include a large number of medicinal plants from Mustang. Therefore, a more comprehensive assessment of annual, biennial and perennial plants within the natural habitat or at the study site would help improve our understanding of impacts of climate change on such plants. Hence, it is recommended that one greenhouse and one research laboratory for phytochemistry be established in a high altitude area of Nepal, like Mustang.

Third, the detailed chemical constituents of these plants need to be analysed and finger prints of all prepared for baseline data, which could be followed up at an interval of ten years to know the real impact on such plants.

Fourth, there is need to establish a national-level natural product laboratory to commercialize and manage these traditional knowledge and natural resources. Phytochemical and ethnopharmacological relevant programmes should be integrated in the up and coming climate change management projects in the country. It is also recommended to draw the government's attention to the fact that, instead of exporting them in crude form, they can be converted into low volume high value products, which can be done within the country by Nepalese scientists.

Future Research

There is need for establishing a greenhouse either in Lete or in Jomsom in Mustang in real climatic conditions and medicinal plants cultivated there in two different temperatures to know the real impact on selected medicinal plants. Our plan is to establish a greenhouse either by ourselves or in collaboration with the Temperate Region Research Centre of GoN in Mustang. Next, we will work in more detail than this project if funding is forthcoming. Relevant phytochemical and ethnopharmacological knowledge will be used in low volume high value products, which is possible in our laboratories.

Conclusion

Herbal resource-based traditional medication practices in the lower Mustang area have been found influenced by the impact of climate change on herbal drugs. Impact of climate change on medicinal plants is seen mainly in respect of accessibility, yield, efficacy and chemistry. To find an alternative source, some *Amchis* have started cultivating some medicinal plants in private lands. In the experimental greenhouse model, while they were cultivated at 5°C temperature difference, with average 5% relative humidity difference, the temperature stress on medicinal plants has been seen in the morphology and chemistry, ie secondary metabolites of the plants. Plants grown in warm conditions were taller with thicker stem, and those cultivated in lower temperature had large leaf size and root size and higher moisture content. Necrosis of leaf in warmer conditions was observed in some plants. Similarly, shoot number, root length, stem thickness, etc were also negatively influenced by high temperature. Chemical analysis showed that some of pharmacologically active compounds were inhibited in high temperature. Pharmacological activity also showed variations in the action of these plants in cytotoxic anti-inflammatory and antimicrobial properties.

CARBON SEQUESTRATION IN A FIRE-AFFECTED ECOSYSTEM OF *Pinus roxburghii* FOREST IN RASUWA DISTRICT, NEPAL

Biva Aryal[1], Bishnu Prasad Bhattarai[1], Mohan Pandey[1], Sushma Devkota[1]

Executive Summary

Climate change caused by an increase in the concentration of carbon dioxide (CO_2) in the atmosphere is a major concern worldwide. Naturally, forests play a significant role in balancing the amount of CO_2 through carbon (C) sequestration, and they ultimately mitigate the impacts of the climate change. By contrast, forest fires alter the C cycle by emission of CO_2 in atmosphere and conversion of forest biomass (plant parts) into black C (char, charcoal, etc). In this background, the present study aimed to determine the impact of fire and its role in either contribution to mitigation of atmospheric CO_2. Therefore, the study was carried out in the *Pinus roxburghii* forests of Rasuwa where annual fires on forest floor with different intensity is common. We measured total C stock (vegetation and soil) of sites of different intensities, namely high frequency and high intensity (HFHI), high frequency and moderate intensity (HFMI), high frequency and low intensity (HFLI), as well as unfired (CON) sites. The statistical analyses showed the highest total C stock in HFMI (1665.40t/ha). This strongly suggested that forest floor fires of medium intensity promote CO_2 mitigation (6106.5t/ha). Likewise, relatively low total C stock in HFHI (1471.83t/ha) with low coverage of ground vegetation suggested that the high intensity fire neither is efficient for CO_2 mitigation nor helps to maintain the forest. Therefore, to avoid the risk from high intensity fire, as well as extensive fire, biomass collection or controlled fires at regular interval before huge collection is recommended. In Nepal, there is no strict policy on the management of forest fires. The findings of the present study could be helpful in formulating policies on the management of forest fires in *P. roxburghii* forests to some extent. Further study of the regeneration pattern of fire-prone species is suggested.

[1] Society of Natural Resource Conservation and Development, Kathmandu

Context and Importance

Fire is one of the reasons for imbalance of atmospheric CO_2—the main cause of global climate change. In Nepal, forests are frequently affected by fire, and the intensity of fire differs variably between the protected and non-protected areas. The policy on forest fire has not been implemented so far. In some protected areas, controlled fire and collection of ground biomass have been practised by the authorities. In non-protected areas, and sometimes in protected areas, however, forest fires happen accidentally or intentionally. In Rasuwa, the *P. roxburghii* forest is heavily influenced by frequent forest floor fires due to presence of a highly flammable substance, resin, in their plant parts (Kumar, 2015; Paudyal, 2008). Based on their effects on vegetation, forest fires can be categorized either as forest floor or as extensive. The former affects ground vegetation, ie herbs, shrubs and tree saplings, while the latter affects the whole forest. During forest fires, significant amounts of CO_2 are emitted to the atmosphere. Simultaneously, after fire a fraction of the burning vegetation and soil organic matter is converted to black C which exists as a continuum of char, charcoal (Turcios, *et al.,* 2015; Hart, *et al.,* 2008). The amount of CO_2 emission and production of black C, however, differ significantly and depend on the intensity of fire, which, in turn, depends on accumulation of forest biomass on the ground. Despite this potential significance, the total C stock, including distribution of black C pool, which is important for projections of future climate change, is poorly understood.

Research Findings

The total carbon sequestration of forest includes capture and storage of atmospheric CO_2 in plant parts (vegetation sequestration) and storage in the soil (soil sequestration). In the present study, the maximum C stored was found in *P. roxburghii* plants and minimum in *Rhododendron arboreum* and *Lyonia ovalifolia* in all four sites. Similarly, among the four sites, total C stored in vegetation was higher in the HFMI and HFHI sites and the lowest in the CON site and intermediate in the HFLI site. The highest C stock of *P. roxburghii* in the fire-affected ecosystem suggested its fire-resistance capacity that can tolerate forest floor fires of different intensity. The fire of different intensity caused both positive and negative impacts on the *P. roxburghii* forest. Although fires up to medium intensity promote C sequestration, high intensity affects the existence and ultimately the diversity of other associated tree species.

In fire affected forest, soil C may be stored in the form of charcoal and soil organic carbon (SOC). In this study, we measured charcoal and SOC stocks at different depths of soil. Our measurements showed that fire increased the amount of SOC. Compared to the CON site, the SOC stock was higher after fire. Likewise, compared with SOC at different depths, SOC stock gradually decreased with increasing soil depth. In all fire sites, charcoal was distributed from 0-30cm depth. Overall, the total charcoal stock (%) was the highest in top soil (0-2cm, 53%), followed by 2-10cm and the lowest (42%) was recorded at 10-30cm depth at all fire sites. Among the four sites, the highest amount of charcoal was recorded in a deep layer (10-30cm) of the HFMI site. The high value of soil carbon stock in fire sites promotes addition of C in soil and its accumulation at different depths by the leaching process favours the sink of C as a long-term C pool. Among the four sites, the total C sequestration (sum of vegetation and soil C sequestration) was the highest at the HFMI site, which suggested that the forest floor fire of medium intensity has positive impact on CO_2 mitigation.

Decomposition by microorganisms and respiration by roots are the major processes that release CO_2 back to the atmosphere. The amount of CO_2 released can be measured by CO_2 flux, which depends on the amount of water in soil (volumetric water content; VWC percentage) and soil temperature. The CO_2 flux increased with increasing VWC (%) and decreasing soil temperature. Results of the CO_2 flux in this study showed gradual decrease from HFLI<HFMI<HFHI respectively. The highest CO_2 flux recorded in HFLI indicates that microbial activities and root respiration are high even after fire. It suggests that fire of low intensity left floor biomass partially burnt, which is suitable for microbial decomposition.

Plants are the main components that can capture atmospheric CO_2; thus, they help in CO_2 mitigation. In our study, the higher to lower value of total CO_2 mitigation was obtained as 6106.51t/ha, 5396.76t/ha, 4601.91t/ha and 3396.79t/ha in HFMI, HFHI, HFLI, CON respectively. The overall study suggested that fire up to medium intensity not only supports CO_2 mitigation but also favours the maintenance of the ecosystems by allowing the growth of ground vegetation and even microbial activities in soil. By contrast, the scenario is reversed, ie less ground vegetation and low microbial activities, in case of HFHI, although the data of CO_2 mitigation is close to HFMI.

Methods

The study was carried out in Dhunche and Syapru VDCs in Rasuwa district. In both VDCs, *P. roxburghii* forests located along the Trishuli River up to the Pasang Lhamu Highway are frequently set on fire (park authorities, local communication, visual observation). We selected three categories of fire intensity and frequency sites, namely high frequency and high intensity, high frequency and moderate intensity, high frequency and low intensity, and control (unfired) site on the basis of collecting the basic data: height of ground vegetation (Armour, *et al.*, 1984), charcoal accumulation on ground (Turcios, *et al.,* 2015), needle accumulation, burn level on tree trunks of pine and other species (Fire Science Brief, 2009), location of live trees (James, *et al.,* 1985), coverage of bare land, number of burnt species, etc. Random sampling method was used for forest inventory surveyed. The biomass sampling was done with the help of three nested circular plots of radii from the centre of tree circular plots of radii 10m, 5m and 2.5m for trees, saplings and shrubs respectively. Trees species with DBH>10cm and height>1m were considered as a tree. The latitude and longitude of each tree were measured to make the plot permanent for future studies. Species which have height <1m were considered as shrubs (Shrestha and Singh, 2008). Diameter at breast height (DBH) and height of each tree within each plot were measured. Biomass data were used to analyse carbon stock. Wood and foliage carbons were analysed according to Negi, *et al.*, 2003. Branch carbons and below ground carbons were analysed by Oli and Shrestha (2009). Soil samples were collected from different depths (0-2, 2-10, 10-30, >30cm) with the help of core ring used for bulk density (Blake and Hartge, 1986). Charcoal and soil organic carbon stocks were analysed in laboratories using standard protocol. Similarly, CO_2 flux, soil moisture and soil temperature were recorded.

Recommendations

The Climate Change Policy of Nepal 2011 includes the provision of expanding the scope of carbon sequestration through scientific management of forests, formulating and implementing land use plans and controlling deforestation. Although the existing policy acknowledges deforestation as a major contributor of CO_2 to the atmosphere, the impact of forest fire and its role in carbon sequestration is missing.

The current policy also focuses on generating financial resources by promoting carbon trade and clean development mechanism. Generally, the carbon credit cost calculation is based only on vegetation sequestration. The finding of the present study suggested that C is also stored in the soil for a long time in the fire-affected ecosystems. Therefore, the value of soil carbon should also be included in the calculation of the total carbon credit. The present study forms a scientific basis for carbon trade, which will ultimately help to improve the current policy on the impact of forest fire on climate change. The recommendations presented here are mainly based on the study carried out inside the national park where the fire has been monitored by park authorities. As *P. roxburghii* forests, which contribute high CO_2 mitigation even after a fire, are distributed throughout the country, the recommendations will be useful to the GoN in developing a forest national fire policy, which will help to manage *P. roxburghii* forests. The recommendations are as follows:

- The high frequency of fire reduces the chance of extensive fire due to shortage of fuel mass (litter) on the forest floor. Therefore, either removal of the fuel mass from forest floor or controlled fire should be practised at regular interval before accumulation of huge mass.
- Park/authorities should encourage the local people to collect *P. roxburghii* needles from the forest, which will minimize the accumulation of fuel mass on the forest floor.
- The chance of fire is high if the fuel mass on the forest floor and branches of trees with needles are close together. Therefore, the thinning process in which the lower branches of pine trees are removed can help avoid extensive fire.
- Local people and park authorities should be alert to forest fires. Forest floor fire is not very serious for the environment; however, if the fire level is up to the crown, then it will be necessary to control it.
- The authorities should contribute to formulating a forest fire management policy with the help of scientific community. Fire management actions can mitigate the risk of high severity fires and discourage extensive fire events in the future.

Future Research

Fire can change the carbon cycle amount of CO_2 due to either emission during forest fire or conversion of forest biomass (litter and plant parts) into charcoal. The CO_2 emission contributes to climate change; however, charcoal deposited in the soil again acts as a carbon reservoir for long term. The present study dealt with the forest floor fire of different intensities and the result suggested that fire of medium intensity is conducive to high total carbon sequestration. The future research questions that emerged from this research are as follows:

- The dominance of *P. roxburghii* in all forest fire sites and *Indigofera pulchella* in low and medium intensity sites suggested their fire-resistant capacity. It will be interesting to study the fire-tolerant potential of these plants.
- The low number of saplings and seedlings of *P. roxburghii* and other associated species in the fire-affected sites can be another research topic to determine the regeneration status in fired ecosystem.
- In Rasuwa, two extensive fire events in the coniferous forests are known so far: one is in Chandanbari and another in Gatlang. The extensive forest fire sites showed poor regeneration; thus, it is important to know the ecological features responsible for it.
- The rate of carbon sequestration should be measured every year in a fire ecosystem to determine the actual amount of CO_2 capture by the plants.
- Similarly, the amount of CO_2 emission during a forest fire can be measured to determine the emission rate.

Conclusion

Surface fire is limited to low heights and does not damage *P. roxburghii* trees. Thus, it is helpful in carbon sequestratation supporting climate change mitigation. We concluded that the controlled surface fire is beneficial to the global carbon mitigation in case of *P. roxburghii* forests. The study conducted in three different fire frequencies and intensity sites suggested that in terms of CO_2 mitigation and long-term C pool HFMI fire condition could be an appropriate option. However, the HFHI site with low ground vegetation with few associated species suggested that high intensity surface fire reduces the overall diversity because only fire-prone species can grow in such areas.

Sometimes, high intensity surface fires are the cause of extensive fire; they release CO_2 to the environment and destroy large areas of land and affects C sequestration. Therefore, the study suggested that fire up to medium intensity can be practised in *P. roxburghii* forests.

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Paulownia tomentosa, A FAST-GROWING TREE WITH MULTIPLE BENEFITS: EFFECTIVE TO ABATE THE CHANGING CLIMATE

Lila Bahadur Magar[1], Nisha Shrestha[1], Saraswati Khadka[1], Jay Raj Joshi[1] Jiba Raj Acharya[1], Gaurav Chandra Gyawali[1], Bishnu Prasad Marasaini[1], Sabari Rajbahak[1], Niranjan Parajuli[1]

Executive Summary

Paulownia tomentosa is a fast-growing perennial large leaf plant. It is native to China but is also commercially cultivated in other parts of the world. Although this plant is recognized as a commercially important plant in other parts of the world, its contribution seems to be neglected in Nepal. The Government of Nepal has no national policies or legislation on international trade in its timber. In addition, *P. tomentosa* is one of the best plants adopted in the agro-forestry programme in community forests, an important strategy to abate the global climate change. This study was based on micro-propagation of *P. tomentosa*, optimizing the technique for higher survival rate, and it monitors the plant's CO^2 sequestration ability and makes a comparative study of CO_2 sequestration potential in plants that are newly planted, previously planted and *in vitro* condition. Micro-propagation technique showed that the combination of hormone with 1.0 mg/ml BAP (Benzyl aminopurine) and 0.1 mg/ml NAA (Naphthalene acetic acid) provided the best results for shoot induction. Drawing on the results of newly planted and previously planted *P. tomentosa,* this brief provides baseline information on CO_2 sequestration potential of the community-managed forests of *P. tomentosa*. These results could be evidence for national policymakers to formulate national policies on global warming and climate change considering *P. tomentosa* to promote community forests.

Context and Importance

Nepal's contribution to the global annual GHG emission is 0.025% (MoPE, 2004). The total GHG emission from Nepal is estimated at 39,265 Gigagram (Gg) and per capita emission is 1,977 kg (MoEST, 2008a). The consequences of global warming have already been seen in different parts of Nepal. Natural disasters like floods, landslides, droughts or excessive rain, soil wastage in stream areas, and glacier recession are some key impacts of climate change. Rain has been less predictable and dependable in terms of both distribution and amount. There has been less snow and more ice (ICIMOD, 2006). In addition, it has shown severe negative impact on various sectors like forests, water resources, agriculture, human health and biodiversity in Nepal. The continual loss of fresh water resources and wetlands and extreme weather conditions have become major problems these days.

Reforestation is a very simple and cost-effective solution to abate climate change. Forests function as a source of emission and as a viable sink of atmospheric carbon. Sustainable management of community forests will be a milestone in trade-off with carbon emissions. The reforestation programme via *P. tomentosa* will be an important strategy to minimize the impact of climate change, reduce soil erosion and create habitats for wildlife species. Moreover, planting of this species within communities will improve the ecosystem's capacity for CO^2 sequestration, which will ultimately help to minimize the impact of climate change, reduce soil erosion and improve the livelihood options of the community people.

Research Findings

Micro propagation—a powerful technique to generate large numbers of healthy plants within a short period of time—was used to propagate *P. tomentosa,* indicating that concentration of hormones BAP at 1.0 mg/l and NAA at 0.1 mg/l provided the best results of shoot induction. Godawari National Park in Lalitpur,

[1] National College, Kathmandu

Kathmandu Valley, was selected for measuring the CO_2 sequestration of previously planted plants. About thirty plants were planted in a row at the southern gate of the park in June 2011. Data were collected for five different periods within a year. The average CO_2 sequestration by *P. tomentosa* at Godawari Botanical Garden was found to be 1489.38 ± 489.91, 1882.03± 537.97, 954.96 ± 578.77 1994.56 ± 606.77 and 2068.41 ± 610.196 kg during the first, second, third, fourth and fifth phases respectively. The difference within nine months was found to be 579.03 ± 101.68 kg.

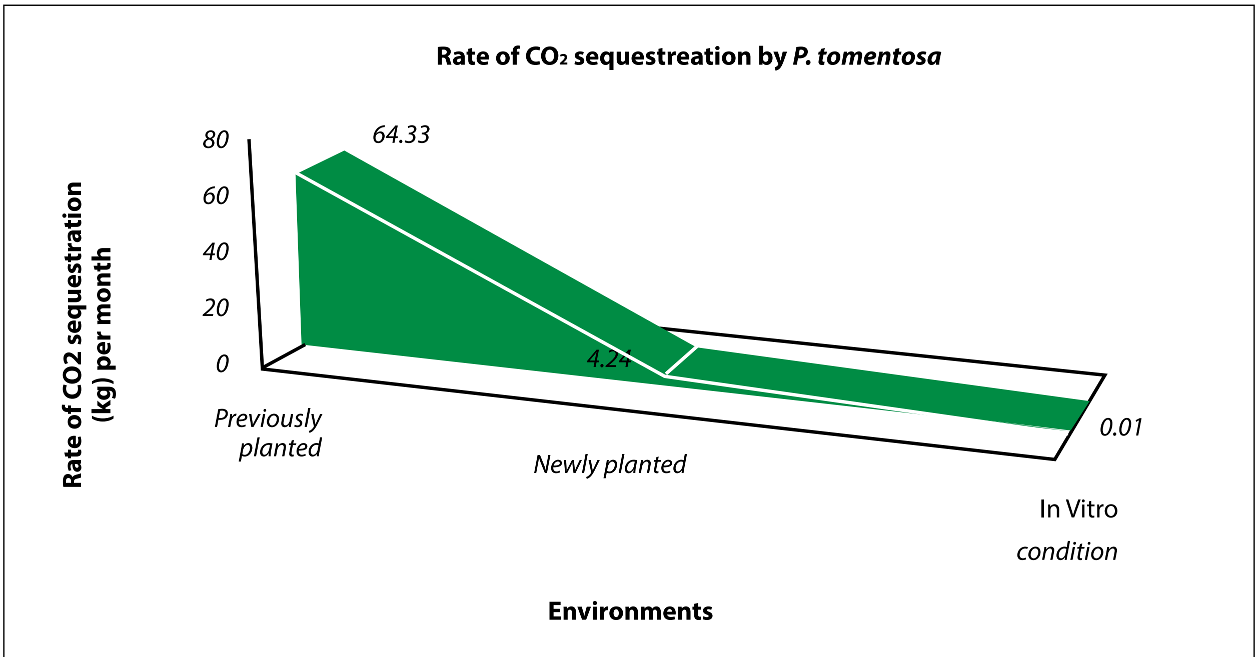
Likewise, Bhimesthan-5 in Sindhuli district was selected as the site for measuring the CO_2 sequestration of newly planted one-year-old *P. tomentosa*. Average CO_2 sequestration by newly planted *P. tomentosa* Steud was found to be 8.092 ± 1.98, 13.68 ± 2.8, 29.33 ± 5.37 kg during the first second and third phases respectively. The difference within five months was found to be 21.24 ± 6.35 kg.

The average CO_2 sequestered by plants at *in vitro* condition was 0.031 ± 0.01, 0.069 ± 0.01, 0.084 ± 0.01 kg during the first, second and third phases respectively. Difference within five months was found to be 0.053 ± 0.01 kg.

Table: Rate of CO_2 sequestration per month by *P. tomentosa* in two different environments

Environments	Plant No.	Total months	Difference of CO_2 sequestration (kg)	Rate of CO_2 sequestration (kg)
Previously planted	30	9	579.03 ± 101.68	64.33 ± 11.29
Newly planted	100	5	21.24 ± 6.35	4.24 ± 1.27
In vitro condition	100	5	0.053 ± 0.01	0.01 ± 0.002

Figure: Rate of CO_2 sequestration by *P. tomentosa* in three different environments



Methods

CO_2 sequestration of *P. tomentosa*

Determination of total green weight of tree

For trees with D< 11, GW= 0.25D2H; for trees with D>= 11, GW= 0.15D2H

Where, GW= above ground tree in pound, D= diameter of trunk in inch and H= height of trees in feet (Broward, *et al.*, 2012).

Determination of dry weight of tree

The average tree is 72.5% dry matter and 27.5% moisture. Therefore, to determine the dry weight of trees the green weight of the tree is multiplied by 72.5%.

DW= GW* 72.5%

Where, DW= Total dry weight of the tree, GW= Total green weight of the tree

Determination of the weight of carbon in trees

The average carbon content is generally 50% of the tree's total volume. Therefore, to determine the weight of the carbon in trees, the dry weight of the tree is multiplied by 50%.

Below ground biomass

The relationship between root (below ground) to shoot (above ground) biomass is the root to shoot ratio. MacDicken (1997) recommends that the root to shoot ratio is 1:5; that is, below ground biomass is estimated as 20% of above ground biomass.

Total carbon stock density = above ground biomass + below ground biomass

Determination of CO_2 sequestration in trees

CO_2 is composed of one of carbon and two molecules of oxygen. The atomic weight of carbon and oxygen= 12.001115 and 15.9994 respectively. The weight of CO_2 (C+ 2*O) = 43.999915. The ratio of CO_2 to C= 43.999915/12.001115= 3.6663. Therefore, to determine the weight of the CO_2 sequestered in trees, the weight of the total carbon stock density is multiplied by 3.6663 (Pearson, *et al.,* 2007).

In vitro* propagation of *P. tomentosa

Using freshly prepared Mercuric chloride (0.1%) and Sodium hypochlorite (1%) for 5–7 minutes surface sterilization was done. Single nodal explants were inoculated on to MS medium. Different concentrations of plant growth regulators were tested for shoot induction. MS medium was supplemented with 0.5 mg/l, 1.0 mg/l, 2.0 mg/l, 2.5 mg/l and 5.0 mg/l BAP and 0.1mg/l IAA, KN and NAA. Sucrose (3%) was used as carbon source and pH was adjusted to 5.8 before autoclave. Single node culture was done on MS medium. Subculture process was performed four or five times. After four or five successive *in vitro* proliferations of explants, they were moved to a polyhouse for acclimatization for ten days. Plantlets were removed from media and sand rooting was done. The temperature and humidity of the polyhouse were maintained at 20 ± 5ºC and 80% respectively. Plants were assessed for rooting at two to six weeks. After six weeks, plants were transferred into soil bags (Rajbahak, *et al.,* 2014).

Recommendations

Kathmandu has been ranked the third most polluted city in the world (pollution index, 2016). Burning of fossil fuel by automobiles and brick factories is the major source for the production of greenhouse gases in the capital city and other cities of Nepal. It is difficult to control air pollution in urban areas of Nepal due to unmanaged urban development and congested traffic. Thus, one option to mitigate the emission of greenhouse gases is to increase the carbon storage/ sinks in wood.

P. tomentosa is a fast-growing tree with multiple economic benefits. It grows up to 12–15m. The timber of *Paulownia* is light but strong. It has a high strength-to-weight ratio and low shrinkage coefficient; hence, it does not easily warp or crack. The wood also has better insulation properties (Chunchukov and Yancheva, 2015), and considering its large leaves, 50–60cm in diameter arranged in opposite pairs of stem (Rahman, *et al.,* 2013), it highly supports CO_2 sequestration. In our study, we have estimated the amount of CO_2 sequestration ability of the *P. tomentosa* in three different environments, viz previously planted plants, newly planted plants and plants *in vitro* condition. Measurements taken at different months indicate gradual increase in ability to sequester CO_2, but the data obtained from *in vitro* CO_2 sequestration was negligible. The data generated in this study is comparable with those of previous reports (Banskota and Karky, 2006), which suggests that older forests have higher CO_2 sequestration ability than regenerative forests. Comparative study of CO_2 sequestration in the three environments indicates that the ability of CO_2 sequestration by previously planted plants is stronger than the plants in other environments. The rate of CO_2 sequestration of older *P. tomesntosa* was found to be 64.33 ± 11.29kg per month. Hence, multipurpose trees like *P. tomentosa* could be an option to reduce CO_2 in the atmosphere of Nepal.

Although *P. tomentosa* is recognized as a commercially important plant in other parts of the world, its contribution seems to be neglected in Nepal. The GoN has no national policy or legislation on international trade in this plant. Therefore, a national policy should be formulated to fix royalty rates for forest products of new tree species like *P. tomentosa*. Consequently, the number of farmers that cultivate *P. tomentosa* will increase and the country can benefit from international trade in timber and also mitigate the impacts of climate change.

Future Research

- Sequestration of CO_2 in forests is necessary to strengthen the data obtained.
- Below ground sequestration should be done to add validation to data.
- Tissue culture methods should be further optimized for getting better results in acclimatization.

Conclusion

This study indicated that older plants have higher ability to sequester CO_2. The rate of CO_2 sequestration by *P. tomentosa* was found to be significant, which can be implemented in forests to mitigate the impacts of changing climate.

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EFFECTS OF CLIMATE CHANGE ON SECONDARY METABOLITE PRODUCTION IN LICHEN OF NEPAL

Bishnu Prasad Neupane[1], Kamal Prasad Malla[1], Anil Gautam[1], Pramesh Paudel[1], Nirmala Jamarkattel[1]

Executive Summary

Interest in climate change has increased tremendously in the past ten to fifteen years, both within and outside the scientific community. The reason for this interest is directly related to the anticipated global warming that will result from increased concentration of greenhouse gases in the atmosphere. Understanding and predicting the responses to climate change is essential to long-term conservation strategy (Hannah *et al.,* 2002). Research to examine the species response to climate change needs to draw complementary datasets from observations and functional analyses, covering changed species interactions and chemical compositions. Global climate change conditions often alter plant chemical composition, which, in turn, can affect food and fodder quality and decomposition rates (Warren, *et al.*, 2003). These alterations in the chemical composition of plants grown under current climate can give significant information on the impact of climate change on synthesis of secondary metabolites. Therefore, it is pertinent to investigate the effects of climate change on production of plant chemical composition. The government is advised to shift the research policy from field-based observation to scientific and real, practical and laboratory data-based research that would give virgin information from the ground level. Nepal is rich in biodiversity and the government and other stakeholders should identify the key species directly responding to climate change effects for future prediction and climate change adaptation. Lichen is one such species found in Nepal. A controlled experiment on lichen would give vital information about the climate change happening in the Himalayan region.

[1] School of Health and Allied Science, Pokhara University, Kaski

Context and Importance

According to climate scientists, a long-term change in the earth's climate is likely to continue over this century and beyond. The main reason for this is the increased concentration of carbon dioxide and other heat-tapping greenhouse gases that human activities produce. A number of studies show that Nepal is among the countries highly vulnerable to climate change. Climate change has both direct and indirect negative impacts on the general well-being of people. It is undisputable that climate change will result in food insecurity, notably in rural areas. The impact of climate change, particularly at the grass roots level is noticed in terms of deficit in food production due to natural hazards such as droughts and floods, which have been ravaging the country for many years and are increasing in both frequency and intensity. Shortages of water and food and the changing spread of disease vectors will all lead to greater health and life risks. Agricultural crop yields are also expected to be affected by changes in climate in terms of precipitation, temperature and CO_2 levels. Temperature and precipitations have been the major climate variability and observed climate change indicators. The measurement of these variables at time intervals under natural and controlled conditions is essential to minimize the risks of climate change.

Research Findings

The usnic acid contents of the samples of thirty-one lichens *(Parmelia flexilis)* collected from the local altitude gradients in Kaski district are determined by high performance liquid chromatography (HPLC), and the relationship between the amounts of usnic acid and altitude is tested statistically. It was found that the usnic acid content in the samples of the dry lichen varied from the highest 5.13% to the lowest 1.66%. The species collected from lower altitudes possess high levels of usnic acid. The negative relationship between usnic acid and altitude was obtained with regression coefficient -001432. It means that the content of usnic acid significantly decreases with increasing altitude. Statistically, a significant difference was found between the average percentages of usnic acid in three groups of altitudes ($p<0.05$). Moreover, the findings showed that the lichens growing in Nepalese climate are responding to the climate in different altitudes. The major climate variables responsible for the change would be the temperature and precipitation patterns. In general, the temperature decreases with the increasing altitude, but the recent trend shows that the average temperature is moderately increasing with altitude due to global warming. The research found that the lichen metabolite is directly responding with these increasing temperatures at different altitudes.

Methods

Thirty-one samples of the lichen species, *Parmelia flexilis,* grown at different altitudes with varying climatic conditions in Kaski district were collected by random sampling methods between April and May 2015. The National Herbarium and Plant Laboratory, Godawari, collected the samples from their herbariums. Foreign matters were segregated from the collected samples and oven dried at 80°C. The dried samples were powdered and extracted with acetone solvents. The extracts were further purified and presence of usnic acid was identified under a UV-chamber by a thin layer chromatography (TLC) using solvent system (toluene 200 mL: glacial acetic acid 30 mL) along with standard usnic acid obtained from sigma-Aldrich, Germany. The analysis was done in Agilent 1290 HPLC system equipped with diode-array detector (DAD) and autosampler, and reverse phase C18, 5 µm particle size in a 250 mm x 4.6 mm I.D. stainless steel column was used. Flow rate was 0.8 ml/min. For usnic acid detection at 245 nm, a mixture of methanol and phosphate buffer (pH 7.4) (70: 30 v/v) was used as mobile phase. Of the extracts 20µl aliquots were injected into the HPLC system. Each analysis was carried out in triplicate. Calibration curve for usnic acid was obtained with five samples of various concentrations (20 mg/L–100 mg/L) using the linear regression analysis. The data obtained from the HPLC about the content of usnic acid was statistically analysed and correlated with altitudes from where the samples were collected.

Recommendations

Among 20,000 species of lichens in the world, around 2,000 are found in Nepal. Further research could be done on the lichen communities to explore the climate change signalling secondary metabolites under natural and controlled conditions. Nepal is rich in biodiversity, and the government and other stakeholders should identify the key species directly responding to climate change effects for future prediction and climate change adaptation. The government, in coordination with the local community and academics, should focus its efforts on conserving biodiversity. The local healthcare practices prevalent in different communities should be preserved for adaptation against climate change impacts. The use of synthetic drugs and its improper management are also causes of climate change. In this regard, the government must realize the hidden potential granted by nature and make practical policies for their conservation. There is a big gap between scientists and policymakers. The climate change-related policies and recent scenarios should be shared with researchers so that they can investigate the findings contributing to national as well as international community to better adapt to climate change impacts. There are various areas like agriculture, high altitude medicinal plants, tourism, public health and so on for future research in the field of climate change. At the end, integrative and interdisciplinary climate change research projects should be carried out for pinpointing outcomes.

Conclusion

A secondary metabolite usnic acid produced in the lichen species, *Parmelia flexilis,* found in local altitude gradients in Kaski district of Nepal are quantified. It is found between 1.66 and 5.13%. A negative relationship is observed between the concentration of usnic acid and altitude, which means the amount of usnic acid decreases with increasing altitude. This trend was statistically tested and found significant. Therefore, the results can be linked to climate change since usnic acid directly responded to climatic variables like temperature and precipitation at different altitude gradients. The findings can be used as baseline research data on climate change to document the Nepalese lichen as a climate change indicator in response to global warming.

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RIVER ECOLOGICAL STUDY: ASSESSING THE CLIMATE CHANGE AND BUILDING A BASE FOR ADAPTATION

Bibhuti Ranjan Jha[1], Smriti Gurung[1], Kumar Khatri[2], Bikash Gurung[3], Shekhar Acharya[3], Anuja Thapa[1], Mamta K.C.[3], Rabindra Kayastha[1]

Executive Summary

The proposed research work, titled 'River Ecological Study: Assessing the Climate Change and Building the Base for Adaptation' tries to build primary or baseline information of Nepalese rivers and their water quality and resources, including fisheries, macroinvertebrates and substrates in a holistic manner. It is expected to have widespread application in hydropower and irrigation, drinking water supply, fisheries and aquaculture, mining and quarries, water transport and recreation, land use planning, biodiversity conservation and climate change.

Water remains the most important of all natural resources in the country, upon which development and prosperity directly depend. Among water resources, the rivers and streams number in thousands and exceed 45,000km in length and covering 39,5000ha of surface. Another important resource directly associated with water bodies is fisheries, on which information is scant and largely descriptive, complicated by the size of country's water resources, as well as its location and physiography.

The distribution and composition of 8,940 varied species of fishes captured from eight sites, categorized as tributaries of the glacier-fed river, Tamor, and rain/spring-fed river, Kamala, showed some signs of climate change, as is evident from the analysis of scientific real-time fish/river ecological information on the specified rivers and streams. The information, supplemented by the physico-chemical and geological data of the sampled rivers, present almost a complete profile of the sites and is very important for the development of policies on management of aquatic resources with numerous applications. This research has numerous short- and long-term uses and hence needs to be extended to other rivers and streams so that the country is prepared to formulate strategies to adapt to new situations, driven by the effects of climate change. This research provides seemingly simple information and knowledge, yet they are as vital as they are scientific and primary.

Context and Importance

Mainly due to its rural setup and absence of large-scale industrialization, the most important environmental threat Nepal is facing is the climate change. It is presumed that the impacts of climate change will be more severe in Nepal due to its location, physiography, poverty and lack of preparedness to cope with the changes. The last reason is mainly associated with the knowledge, information and ability to use technologies based on science.

Primary data, scientific techniques, awareness, education and capacity building are inherent to this research work. In addition, policymakers, scientists and academia, NGO/INGOs, conservationists and awareness groups, business community, sportspersons, adventurists and the local people will benefit either through on-site interactions or through the comprehensive project report.

This research work is a fish/river ecological study in the rivers and streams in remote eastern areas of Nepal, which clearly are information-deficit areas. Small river tributaries are integral to the river system with tremendous ecological value as they feed the main channel, provide connectivity and increase watershed areas, and act as alternative sites as per the ecological and biological needs of the biotic communities. Although headwaters and their tributaries are recognized as important ecosystems as freshwater resources (Wipfli, *et al.,* 2007; Silveri, 2008)

1 Kathmandu University
2 Tribhuvan University
3 Freelancers

and biodiversity repositories (Meyer, *et al.,* 2007), they are sensitive to disturbances and are deteriorating, and have received very little attention (Jacobsen, *et al.,* 2012; Callanan, *et al.,* 2014).

The output of this research will set a standard on the collection and documentation of information in this field and could be used as reference for all future works. The research will bring forth ecological and morphometric information on the fisheries resources of the selected rivers, viz Maiwa, Mewa and Hewa, the tributaries of the glacier-fed Tamor River and Tawa and Lalleri, the tributaries of the spring/rainfed Kamala River. The fish base information is coupled with the data on macroinvertebrates, physico-chemical conditions and river substrate so as to portrait the complete habitat conditions of aquatic biodiversity. The collection and preservation of fish species to establish a museum will also greatly help in the field of taxonomy and biodiversity conservation. The comparison of data of two areas in all seasons has shown the signs and symptoms of climate change, which are also verified by statistical methods.

The main objective of the proposed research was to analyse and evaluate the effects of climate change by taking fish as an indicator. However, even more important outcome of the proposed research is the preparation of solid foundation of fish/river base information, which could be used in future as a reference to variety of purposes including the study of climate change.

Research Findings

This research has obtained primary scientific information on specified rivers and tributaries in terms of fish, macroinvertebrates, physico-chemical parameters and substrate, as well as their interrelationships so as to prepare a complete profile. The fields of application of such information are numerous, the most important being the assessment of the effects of climate change and making people and the country aware of the possible changes in adaptation. Moreover, the comparison of data between the tributaries of a glacier-fed river and those of a rain/spring-fed river clearly shows the differences that might relate to the differences in the effects of the climate change in these two systems.

Altogether 8,940 fishes belonging to ten families, twenty-two genus and thirty-three species were captured during the entire sampling period comprising eight sampling sites and four seasons. Altogether thirty-two species were captured from all the samplings with the highest number of species from the site, Tawa 3, which is closest to the spring/rainfed system, the Kamala River, and the lowest from Mewa Khola, which is closest to the glacier-fed system, the Tamor River. The highest abundance of the fishes was observed in the same sampling site, Tawa 3, while the lowest in Mewa Khola. It was interesting to note that the site with highest number of species also had the highest abundance of fishes, while the site with lowest number of species had the lowest abundance of fishes. The highest number of fishes was captured in pre-monsoon/summer season, which is only natural as the season is a breeding time for most species and they enter the tributaries for substrate, nutrient, oxygen and safety.

In terms of abundance, which is expressed in catch per unit effort (CPUE), once again Tawa 3 had the highest value (152.1) and Mewa Khola the least (15.24). The yearly average in all seasons was found to be 69.93. Some of the species which are common are *Schistura beavani* (26.14), *Barilius vagra* (8.11) and *Schizothorax richardsonii* (5.15). The species assemblage in the tributaries of the glacier-fed and rain/spring-fed rivers distinctly showed differences as there were thirteen species in the former system and twenty-seven in the latter, with six species being common. It is natural that cool, clean and nutrient-deficit springs harbour less number of fish in terms of both species and number compared to warm and nutrient-rich rivers. In both the systems, one-way ANOVA indicated that the variation in the abundance of various fish species was highly significant.

The study of another important group of biota, macroinvertebrates, in aquatic habitat sampled in this work shows that a total of thirty-nine families representing thirteen orders and three classes were present in total. This does not, however, imply that the same families were observed in both types of streams. Altogether thirty-one and twenty-seven macroinvertebrate families were recorded from the tributaries of the glacier-fed and rain/spring-fed streams respectively. The taxonomic order represented by the highest number of family was found to be Trichoptera (9 families), followed by Ephemeroptera and Diptera (5 families). In the tributaries of the glacier-fed stream, the macroinvertebrate order was found in the series: Trichoptera>Diptera, Ephemeroptera>Odonata>Coleoptera, Hemiptera> Plecoptera, Megaloptera, Haplotaxidae, Arhynchobdelliddae, Decapoda, while in the tributaries of the rainfed stream, it was: Diptera and Ephemeroptera>Trichoptera, Hemiptera> Odonata, Coleoptera, Decapoda> Plecoptera, Megaloptera, Haplotaxidae, Neotaenioglossa, Basommatophora, Decapoda. Arhynchobdelliddae was found only in the tributaries of the glacier-fed streams, whereas Neotaenioglossa and Basommatophora were found only in the tributaries of the rainfed streams.

Apart from biotic characteristics, some abiotic factors also differentiated the tributaries of the glacier-fed and rainfed systems: one-way ANOVA indicated pH to be higher for glacier-fed tributaries while conductivity and temperature was found to be higher for rain/spring-fed tributaries. The study of geology (substratum) too showed some variations in space (tributaries of glacier-fed and rain/spring-fed systems) and time (seasons).

Methods

The method of fish sampling applied in this research was a standard electrofishing by wading method (Jha, 2006; Sharma and Jha, 2012), which is a scientific method accepted all over the world. The fish sampling was done by electrofishing gear in two runs of approximately twenty minutes and the captured fishes were studied for variety of fish base characteristics such as type, abundance, length, weight, sex, etc. A few specimens of all the species were preserved and kept for record as type specimen. Fishes were identified to the species level using the widely used keys for the region (Rajbanshi, 2001; Shrestha, 1990; Shrestha, 1994; Jayram, 1999; Shrestha, 2001; Day, 1878).

For macroinvertebrate sampling qualitative and field-based techniques were applied. Qualitative sampling of macroinvertebrates was done according to Barbour, *et al.* (1999). Macroinvertebrates were collected using handnets with mesh size of 250 µm. Various physico-chemical parameters such as location coordinate, temperature, dissolved oxygen (DO), pH, conductivity, etc were measured on site by using standard probes and GPS device. Substrates of the river were measured by constructing line transects along the river at every 20m depending upon the length of the stretch sampled. When it was not possible to construct the line, consistent visual method was applied.

The number of sampling sites was fixed at 8 (4 each in the tributaries of the glacier-fed and rain/spring-fed rivers) and all the samples had four replicates corresponding to the major seasons. Standard protocols were used to record information. The research was carried out with the direct involvement of experts and skilled team members. Logistic support for research was provided by the Department of Environmental Science and Engineering and the Aquatic Ecology Centre (AEC) of Kathmandu University.

Recommendations

Primary data, scientific techniques, awareness, education and capacity building are inherent to this research work. Being the national and central institution for promoting science and technology, NAST, therefore, has become the institution most concerned with this research. Apart from this report, the analysis of scientific data gathered during this work will continue to be applied in so many ways such as for studying taxonomy, biology and ecology of species, for correcting the IUCN threat categories, establishing various relationships between fish fauna and other biotic and abiotic factors of selected streams and for building a base for the adaptations required by the impact of climate change.

In addition, policymakers, scientists and academia, NGO/INGOs, conservationists, awareness groups, business community, sportspersons, adventurists and the local people either have benefitted through on-site interactions or will benefit through the comprehensive project report.

Considering the diverse and complex ecological systems within the geographical area of the country, the following actions are recommended to conserve aquatic diversity and to build a base for the adaptations required by climate change:

Develop and implement policies to effectively manage the resources associated with rivers such as water, fisheries, stone, gravel and sand.

Promote conservation of aquatic diversity and protection of habitats through responsible government department at both central and local levels with swift coordination.

Strictly implement the regulations to control illegal fishing and other destructive activities in the natural aquatic ecosystem.

Develop an effective and efficient monitoring and watchdog mechanism involving local community.

Design appropriate rules and regulations to enforce the implementation of the aquatic biodiversity conservation and utilization act, updating the Aquatic Animal Protection Act (AAPA) 1960 and the National Wetland Policy 2012.

Ensure that the local communities and local government receive economic incentives of the river-based resources so as to raise their interest in the management of the resources.

Include the scientific information on the rivers, their resources and dynamics in school and college curricula so that knowledge and its transfer get institutionalized.

As Nepal is full of rivers and streams in all its territory, extend this kind of research to all its water bodies. Although seemingly an endless job, it must start in all directions with all-out efforts. The future of this type of research is bright.

Conclusion

Despite similarities in general functions such as connecting watershed and culture, geological functions such as eroding and transporting earthly materials, and ecological functions such as providing breeding grounds and refuge at the time of stress and predators, the tributaries of glacier-fed and rainfed river systems show different characteristics. The comparison of fish assemblage clearly showed differences between the two systems. Cool oligotrophic water of the former system supports less biodiversity compared to the warm and nutrient-rich medium of the latter. The comparison of physico-chemical parameters and macroinvertebrates also complemented the main findings.

The data generated in this study is primary scientific data coming from one of the most data-deficit regions in the world. Hence, these data would serve as a base for further study of water regime, biodiversity and climate change in the region and country.

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CLIMATE CHANGE AND HYDRO-ECOLOGICAL RESPONSES OF GLACIAL MOUNTAIN BASINS IN NEPAL HIMALAYA

Narayan Prasad Ghimire[1], Sudeep Thakuri[2], Neeta Adhikari[3]

Executive Summary

This policy brief presents a summary of research on climate change and hydro-ecological responses aimed at understanding the climate and its potential impacts in the glacial basins. The research analysed the glacio-hydrological response to climate variability, considering the climatic, glaciological and hydrological components at medium–high scale basins with a linked glacier-foreland system. The study was conducted using data from ground-based measurement stations, gridded and reanalysis data products, satellite observations, field survey and samplings.

Mountain environments are considered sensitive to climate change. Most of the station data in both basins indicate an increasing trend of temperature. We observed an increase of 0.042°C yr^{-1} in the Tamor Basin and 0.036°C yr^{-1} in the West Seti Basin from 1975 to 2014. The station data indicates that precipitation has no trend or a slightly positive trend in the Tamor Basin (1960s to 2014), but a significantly negative trend, with a rate of -14.3mm yr^{-1} after early 1990s, while in the West Seti Basin, a continuous negative trend (decreasing) with a rate of -4.2mm yr^{-1} is being observed since 1960s. Glacier surface areas have decreased in both basins. From 1975 to 2014, the glacier surface area in the Tamor Basin has decreased by 0.24 ± 0.29% a^{-1} (453 to 410km^2), and in the West Seti Basin by 0.32 ± 0.30% a^{-1} (336 to 295km^2), higher than in the Tamor Basin. Very low and within the WHO levels of chemical parameters, indicating a safe level of water quality for maintenance of the ecosystem. The results suggest that bicarbonate (HCO_3–) has a significant correlation with Ca^2+and Mg^2+, suggesting carbonate rock weathering as the dominant geochemical process in the region. The concentrations of Ca^2+, Mg^2+, HCO_3– in the water of West Seti are strongly higher than in the waters of the Tamor Basin. We concluded that a drier precipitation conditions of West Seti has strong control on the chemistry of waters.

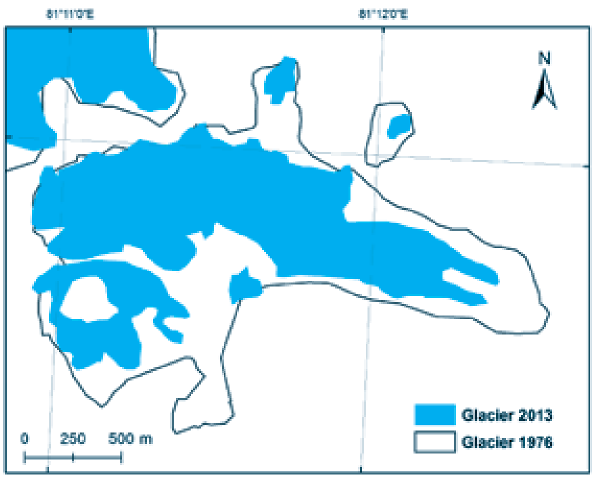
Context and Importance

Himalayan glaciers and ice are receiving increased attention due to their role in the hydrology and climate system (Kaser, *et al.,* 2010; Immerzeel, *et al.*, 2010). Glaciers, ice caps and snow cover play a vital role in storage and supply of melted water to the river flow, which is particularly very important during dry seasons. Aquatic ecosystem and people's livelihoods downstream are directly dependent on these water sources. Water is an essential element for living organisms and constitutes an integral part of our environment. It is important for agriculture, industries and ecosystems, and is treated as a basic requirement for overall development of the country. Warming in the Himalayas has a great impact on the glacier. There is an overwhelming evidence of rapid de-glaciation in the Himalayas. Climate change impact on the hydrological process will have a major effect on livelihoods. The melting of glaciers and changes in seasonality, snowfall and water supply can affect agriculture production, hydropower generation, ecosystem goods and services, and potential increases in the climate-related hazards. All these changes can threaten the sustainability of the people who live in these mountains and downstream in the plains.

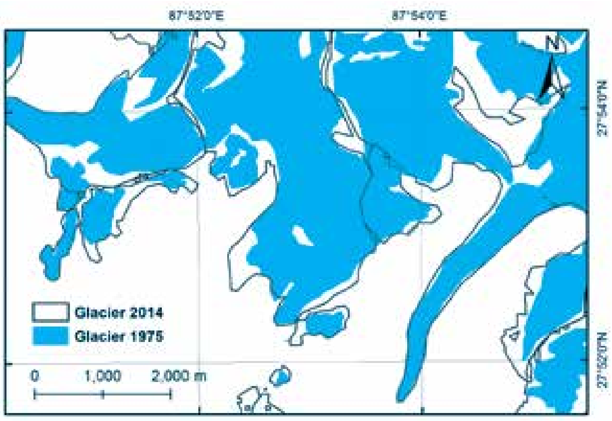
Comprehensive knowledge of the potential impacts of climate on hydrological process is necessary for better understanding the future water availability for human livelihood and for sustaining ecosystem. There are two different research issues: first, human impacts on water

1 Small Mammal Conservation Society, Lalitpur
2 World Wildlife Fund, Kathmandu
3 College of Applied Science, Kathmandu

quality in different water sources; and, second, coupling glacier and hydrological changes to climate variables. Both the studies were conducted in the glacier–foreland system in the Mt Everest region of Nepal. Substantial results have been obtained as output of those studies to advance our knowledge of human and climate change impacts on water quality and hydrological processes. Those studies found that both human activities directly and in the form of climate change are putting pressure on the water resources and increasing the risk of future water availability. Since the 1960s, glaciers have continuously been shrinking (13%) in the Mt Everest region and temperature has been increasing (0.8°C), but precipitation has been decreasing in the last two decades, indicating significant impact of precipitation reduction on glacier's shrinkage in recent times (Thakuri, *et al.,* 2014). The evidence indicates the worsening situation of the glacial and peri-glacial environment. Water resources are the only foreseen main impacts of climate change that can directly threaten access to water and livelihoods.



An example of glacier shrinkage in the West Seti Basin between 1976 and 2013



An example of glacier shrinkage in the Tamor Basin between 1975 and 2014

Research Findings

Glacier surface area has decreased in both the basins. From 1975 to 2014, the glacier surface area in the Tamor Basin has decreased by 453 to 410km^2, while in the West Seti Basin the decrease is by 0.32 ± 0.30% a^{-1} (336 to 295 km^2), higher than in the Tamor Basin.

In general, we observed an increased temperature of 0.042°C yr^{-1} in the Tamor Basin and 0.036°C yr^{-1}in the West Seti Basin from 1975 to 2014. The station data indicates that precipitation has no or slightly positive trend in the Tamor Basin (1960s to 2014), but significantly negative trend at a rate of -14.3mm yr^{-1} after early 1990s, while in the West Seti Basin, a continuous negative trend (decreasing), with a rate of -4.2 mm yr^{-1}, is being observed since 1960s.

The wavelet analysis indicated a significant annual signal (red band between the 256 and 512 days) due to the dominance of monsoon precipitation in both the basins. No significant change in the river discharge signal was observed until around 2000, but we observed non-stationary discharge behaviour starting around 2000 with appearance of additional discharge peak (red band between the period 128 and 256 days), much stronger in the Tamor River than in the West Seti River.

The physico-chemical properties of various water samples of the Tamor and West Seti River Basins are described. The concentrations of Ca^{2+}, Mg^{2+}, HCO_3– in the waters of West Seti are much higher than in the waters of the Tamor Basin. As biological indicator, eight orders of macroinvertebrate families were observed in the West Seti Basin, whereas five order were from the Tamor Basin.

Methods

Ground station data, global and regional climate data products are used for the analysis of spatio-temporal patterns of temperature and precipitation; remotely-sensed satellite data were used for obtaining the basin characteristics and analysing glacier and snowcover changes. Water samples were collected in sterilized bottles and stored at 4°c till further research. Chemicals were used only for analytical reagent grade. The physical parameters—temperature, pH, electric conductivity (EC)—were measured in the field and major ions—Sodium, (Na^+), Calcium (Ca^{2+}), Magnesium (Mg^{2+}), Silica (Si^{4+}), Sulphate ($SO_4^{\ 2-}$), Nitrate (NO^{3-}), Bicarbonate (HCO_3^-), Chloride (Cl^-), Fluoride (Fl^-) in the water samples—were analysed in the laboratory, using standard procedures (APHA 2005). The concentration of Nitrate, Silica and Fluoride is estimated by UV spectrophotometer. Calcium, Magnesium and Sodium ions were estimated by the Atomic Absorpton Spectrophotometer (AAS) method. Sulphate was measured by the Barium chloride titration method, whereas Chloride was measured by titration with silver nitrate solution and bicarbonate alkalinity by sulphuric acid titration. The water samples were assessed by comparing each parameter with the standard limit of that parameter in the National Drinking Water Quality Standards (NDWQS) and World Health Organization (WHO) standards.

Recommendations

a) Further study for obtaining regional perspective

The signs of fast glacial shrinkage in the Himalayas compared to any other part of the world (Cogley, *et al.*, 2010; Bagla, 2009) have focused global attention on necessity of a more comprehensive study in this region. Current uncertainties are mainly attributed to a lack of measurements of both glaciers and climatic forcing agents (Bolch, *et al.*, 2012). The research tried to address these issues in the two basins in the Nepal Himalayas and have shown that temperature and precipitation trends were revealing heterogeneous behaviour in the region. Most of the station data in both basins indicate an increasing trend of temperature, while some stations even show a decreasing trend, but the glaciers have continuously been shrinking since the 1970s. Such fine-scale investigations are needed in other glacier basins for obtaining a regional perspective.

b) Regular water quality monitoring framework at basins

The concentration of chemical parameters is strongly higher in the West Seti River Basin in comparison with the Tamor River Basin. The study of physico-chemical parameters during the pre-monsoon season shows that the flow of major ions and silica to these streams is from chemical weathering during the dry period with low atmospheric activity and low stream flow movement. Thus, drier precipitation conditions of West Seti have strong control on the chemistry of the waters. By establishing a high quality physico-chemical parameter monitoring laboratory for testing water, soil provides an opportunity for further scientific advancement. For example, currently in Nepal, geochemical tracers and isotopic analyses are not possible due to unavailability of test equipment and a laboratory.

c) Assessment of future water availability

The melting of glaciers and changes in seasonality, snowfall and water supply can affect agriculture production, hydropower generation, ecosystem goods and services, and potentially increase climate-related hazards. All these changes can threaten the sustainability of the people who live in these mountains and downstream in the plains.

An improved representative model can be applied to analyse the impacts of climate change on future water availability in these basins, using the latest climate model ensemble.

d) Use of biological indicators

A great potential exist for use of the local biological indicators to monitor the water quality assessment. Organisms like diatoms, microinvertebrates and algae can be used to find out the impact of change on water quality.

e) Vulnerability assessment of local communities and ecosystems

Knowledge is lacking of how future climate scenarios will work and how the whole ecological system respond to the changing climate; however, the vulnerability assessment of the local communities and ecosystems to potential impacts of climate change can provide comprehensive information on the mitigation and adaptation strategy.

Future Research

To gain in-depth knowledge, the following activities can be performed as future research activities:

- Regular monitoring (annual and seasonal) of water quality.
- Identification of the impacts of climate change on future water availability in these basins through the climate model.
- Detailed identification of biological indicators (diatoms, microinvertebrate and algae) to find out the impact of change on water quality.
- Conducting climate change adaptation programmes for local people of these regions.

Conclusion

Temperature and precipitation trends show a heterogeneous behaviour in the region. Most of the station data in both basins indicate an increasing trend of temperature, while some stations even show a decreasing trend. Drier precipitation conditions were found in West Seti compared to the Tamor Basin. The glacier surface area has decreased by 0.29% a^{-1} in the Tamor Basin and slightly higher, by 0.30% a^{-1}, in the West Seti Basin. Any change in the glacier surface causes a change in the river flow. Thus, non-stationary discharge behaviour with additional discharge is stronger in the Tamor River than in the West Seti. The study of physico-chemical parameters during pre-monsoon season shows the flow of major ions and silica to these streams is from chemical weathering during dry period with low atmospheric activity and low stream flow movement. The concentration of chemical parameters is strongly higher in the West Seti River basin in comparison with the Tamor River basin. Thus, drier precipitation conditions of West Seti have strong control on the chemistry of the waters. Such fine-scale investigations should also be done in other glacier basins for obtaining a regional perspective, and climate change adaptation programme should be conducted for the local people of these regions.

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TREELINE SHIFT IN CENTRAL NEPAL HIMALAYA AND CLIMATE RECONSTRUCTION OF PAST MILLENNIA

Yub Raj Dhakal[1], Narayan Prasad Gaire[1], Suman Aryal[2], Santosh Kumar Shah[3], Sanjaya Bhandari[1], Uday Kunwar[4], Santosh Rayamajhi[5]

Executive Summary

Climatic treelines act as bio-monitors for impacts of climate change on high altitude biota. This dendroecological and dendroclimatological study was carried out at the treeline ecotone of two high mountain protected areas of the Nepal Himalayas: Annapurna Conservation Area and Shey-Phoksundo National Park, to assess the impact of climate change on the treeline ecotone and to reconstruct the climatic history of the areas. Using vertical belt transects plots (20m wide and variable length of 100–300m), a detailed ecological and dendrochronological study was carried out. Treeline ecotones of the study areas were formed in some sites by *Abies spectabilis* D. Don, *Betula utilis* D. Don, *Juniperus recurva, Rhododendron campanulatum* and *Sorbus microphylla*. The position of tree and species limit of the treeline forming species were high in the Dolpa region. Regeneration of treeline species varies between species and sites. The size parameters such as tree density, diameter at breast height, height and age of treeline forming trees decreased with increasing elevation and thus decreasing temperatures. The spatio-temporal population age structure of these species showed both stand densification and upward shifting of the treeline in many sites. The treeline was stable to change, depending on the site. The upward shifts of *P. wallichiana* and *A. spectabilis* were more prominent in some sites. Representing each site and species, seven ring-width site chronologies dating back to AD 1569 were developed from *A. spectabilis, B. utilis, Juniperus recurva* and *P. wallichiana.* These chronologies have good dendroclimatic potential. The growth of the treeline forming species was limited by moisture and/or temperature, depending upon the site conditions and moisture regime. The different regeneration patterns of the studied species indicate that the treelines in the study area of the Nepal Himalayas are also subject to changes in the species composition. The reconstructed temperature and precipitation show recent warming but decreasing rainfall during March to June season with long-term fluctuations.

Context and Importance

The Himalayan region is very sensitive and vulnerable to climate change impacts, as rate of change compared to several other regions is more pronounced (IPCC, 2013), and vulnerability is exacerbated by the fragile young geology and poor economic base. Past studies have revealed that the rate of increase in temperature in Nepal Himalayas is more pronounced as compared to many other countries. Though no consistent trend is observed, extreme precipitation events have increased in recent years. Information on the long-term trend in hydro-climatic variation is imperative for evidence-based decision-making and for formulation of appropriate adaptation measures against climate change impacts and other disasters. However, it is a pity that we do not have station-based long-term temperature and precipitation data for long-term trend analysis, which is very essential for realistically projecting future trends, agriculture, forestry and water resources management planning, and preparedness for climate change-induced disasters. On the other hand, due to diverse topography and graded climate, this region has rich natural archives of multi-proxy climatic sources, including tree rings, ice cores and lake sediments, in which tree rings provide high resolution climatic and hydrological data with more accuracy (Fritts, 1976; Speer, 2010). Tree rings are an exceptionally valuable source of paleo-climatic information with spatial scales from a few hectares to a hemisphere and temporal scales from a few hours of an icestorm, through decades of drought, to centuries of changed global atmospheric circulation. Past studies from Nepal have reported several promising tree species for various kinds of dendrochronological research, and

1 Tree Ring Society of Nepal
2 Siddhartha Environmental Services, Kathmandu, Nepal
3 Birbal Sani Institute of Paleo Botany, India
4 University of Minnesota, USA
5 Tribhuvan University, Institute of Forestry, Pokhara

a few dendroclimatic reconstructions (temperature and drought index) that are available (Sano, *et al*., 2005, 2012; Thapa, *et al*., 2014) insufficient to capture climatic variations in the diverse topography of the country and for generalization of the climatic trend for the whole western Nepal Himalayas.

Treeline shift as an influence of climate change has been reported from various parts of the world (Harsch, *et al*., 2009). The Himalayan region and its treelines are, however, largely unexplored (Schickhoff 2005; Gaire, *et al*., 2014), and there is a severe lack of scientific data on climate change and its impacts. The IPCC AR4 report categorizes it under a white spot looking for more scientifically proven evidence. In the changing climate conditions, it is important to understand plant ecology, along with its potential upward shift, as this will have implications for species composition and as the forested area extends, the area of alpine rangelands reduces, which might finally alter the landscape. This, in turn, could negatively impact livelihoods of the marginalized and pastoral communities dependent on the rangeland for collection of non-timber forest products (NTFPs) and livestock herding. Therefore, the current research is relevant in terms of (a) benchmarking the treeline shifts and long-term future monitoring in the project area, (b) reconstructing climatic history for future climate projections, and (c) designing vulnerability and adaptation strategies for community resilience and security of local livelihoods. As the GoN's Climate Change Policy (2011) plans to establish a climate change research centre, the proposed study is in line with this policy framework, which envisages devising an appropriate climate impact forecast tool.

Research Findings

This study was carried out at the treeline ecotones of two high mountain protected areas of the Nepal Himalayas, viz Annapurna Conservation Area and Shey-Phoksundo National Park (SPNP), with the aims of assessing the impact of climate change on the treeline ecotone and of reconstructing climatic history of the areas. The studied treelines were formed by *A. spectabilis, B. utilis, Juniperus recurva* and *Pinus wallichiana, Sorbus microphylla* and *Rhododendron campanulatum. Abies* and *Betula* are the commonly found treeline forming species. Among the study sites, the treeline position was at the highest elevation in Dolpa, with distribution of *Abies, Betula* and *Pinus* at higher elevation compared to other regions. Irrespective of species and sites, the upper species limit ranged from 3,532 to 4,275m in altitude. In some of the sites, regeneration of *P. wallichiana* was better than that of *A. spectabilis* and *B. utilis,* while *Abies* had good regeneration in some plots in Mustang and Manang. The size parameters such as tree density, diameter at breast height, height, and age of trees forming the treeline decreased with increasing elevation. The spatio-temporal population age structure of these species showed both stand densification in most and upward shifting of treeline in some sites. The upward shifts of *P. wallichiana* and *A. spectabilis* were more prominent at some sites. The *Betula utilis* position was stagnant during the recent past several years at many sites. Representing each site and species, seven ring width site chronologies dating back to AD 1569 were developed from *A. spectabilis, B. utilis, Juniperus recurva* and *P. wallichiana.* These chronologies have good dendroclimatic potential. Population demography and growth response studies suggest that trees in the Nepal Himalayas have species-specific and site-dependent responses to climate change. At dry sites, both precipitation and temperature are the major limiting factors for tree growth, while at moist sites temperature is the major limiting factor. Growing season climate has a major influence on the radial growth of these species. Temperature and precipitation from March to June (MAMJ) were reconstructed using the site chronology of *P. wallichiana* from the SPNP. The temperature reconstruction shows different warm and cool episodes with the recent warming. The precipitation reconstruction shows moist and dry periods. There is a slight increase in the precipitation during the 19th and 20th centuries with decreasing trend in the recent few decades. Other studies have also reported similar trends.

The local herders have perceived increasing temperature, decreasing rainfall and decreasing snowfall. These perceptions of herders are supported by the previous studies and predictions for the Himalayan region, which indicate that the perception of the local agro-pastoralists can complement modern science and offer alternative approaches for climate change studies in data-deficit areas. Agro-pastoralists have observed changes in biological indicators such as emergence of new plant species, appearance of new livestock diseases, and changes in physical indicators such as fast melting of snow in the rangelands, increased droughts and drying of water resources. As treelines in some sites are moving upwards, it might have adverse effects on these agro-pastoralist communities who depend on the natural resources near or above the treeline.

Methods

This study followed standard ecological, dendrochronological and social study tools and techniques. Ecological study was done by using belt transect plot methods. The dendrochronological technique used tree core sampling and analysis. Social survey was done by administering questionnaires.

Recommendations

The climate of the study area is changing with several biophysical impacts. The treelines of the study areas of Manang, Mustang and Dolpa are responding to the climate change with changes in the community structure with differential regeneration and stable to changing treeline positions. As the treeline position is changing at many sites, it could have adverse impacts on the rangeland ecosystem situated just above the treeline. The site- and species-specific regeneration and treeline dynamics suggest that future conservation and adaptation measures should be designed considering this differential response to climate change. The reconstructed climate shows long-term fluctuations in the climate. Future research should consider multiple species and multiple sites with the incorporation of multiple factors like abiotic, edaphic and other disturbance factors like grazing, forest fires, etc. for better understanding of the isolated response of species to climate change.

Future Research

Drawing on the findings of this study, the following recommendations are put forward for future study:

1. Studies incorporating all tree species within a plot or site, including shrubs at the treeline, will bring up better ideas for vegetation dynamics in response to the climate change.
2. Differential response is found in diffused and abrupt treelines. In-depth studies are necessary on why they respond to environmental changes differently.
3. Further studies incorporating soil nutrients and characteristics, permafrost layer dynamics, probable allelopathic effects of shrubs on the regeneration, fire dynamics, grazing exclusion and transplantation experiment, masting in seed production, testing of growth or carbon limitation in the treeline formation are essential for further enhancing our understanding of the response of treeline and their dynamics with respect to future climate change.
4. Length and quality of chronology and climate reconstruction can be extended further by searching for old trees and sampling them.

Conclusion

The climate of the study is changing with several biophysical impacts. This study indicated some of the direct and indirect signals of climate change based on observations, dendroclimatic reconstructions and perceptions of local agro-pastoralists. The findings suggest that impacts of climate change have arisen in diverse ways. The site-specific and species-specific regeneration and treeline dynamics demand that future conservation and adaptation measures should be designed considering differential responses of the treeline forming species. The reconstructed climate shows long-term fluctuations in the climate with recent warming temperature but weakening precipitation. It is desirable that future studies consider multiple species and multiple sites with the incorporation of multiple factors like abiotic, edaphic and other disturbance factors like grazing, forest fires, etc for better understanding the isolated response of species to climate change. Study of perceptions and identification of possible impacts help to design adaptation and intervention strategies for the sustainability of traditional farming systems and livelihooda of the local people.

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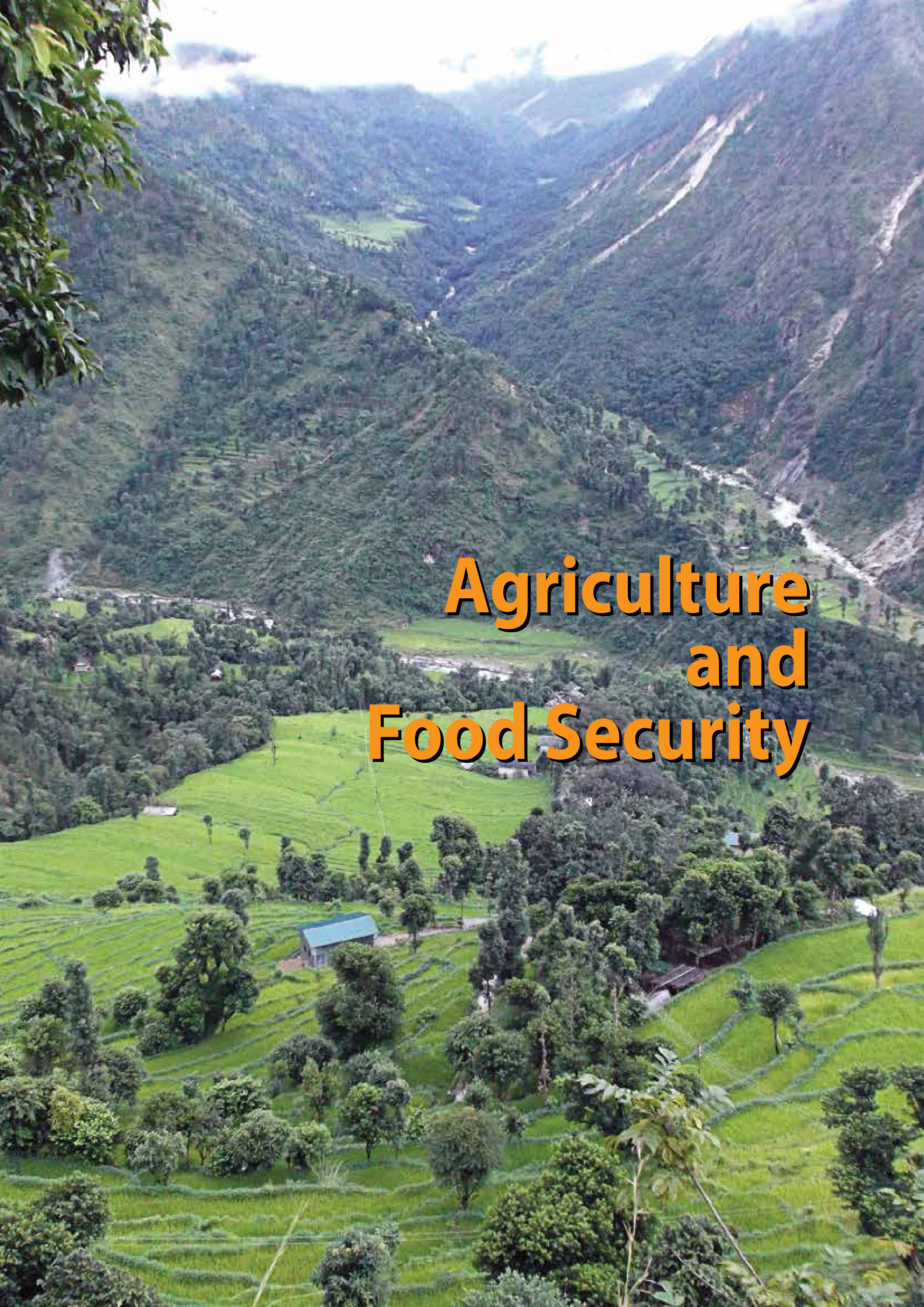

CLIMATE CHANGE IMPACTS ON LIVESTOCK-RAISING AND THE HOUSEHOLD ECONOMY OF MUSTANG DISTRICT, NEPAL

Shreeram Prasad Neopane[1], Suraj Thapa[1], Ananta Koirala[1], Bishwas Sharma[1]

Executive Summary

Nepal is one of the countries most vulnerable to climate change. Climate change is not just an environmental phenomenon but also an economic, social and political issue. Findings from other countries suggest that livestock production has been affected to a great extent by climate change. For Nepalese conditions, however, studies on climate change impacts on livestock are limited.

To address this gap, this study was carried out to reveal the community perceptions of the effects of climate change on their livelihoods, identify and rank the adaptation strategies being employed, and then apply necessary and appropriate technical interventions at the sites. The study was carried out in Mustang district, Nepal during the period March 2015–August 2016. Primary information (the community perceptions of climate change and its effects on livestock production and adaptation strategies) were obtained through household survey, focus group discussion (FGD) and key informant interview (KII). Data were analysed using R software.

The findings showed that the community in the region did experience climate change. The major variables found were the timing and amount of snowfall, temperature, and amount and intensity of rainfall. The community perceived the effects of climate change on livestock production and had adopted adaptation measures to cope with the change. The major effects of climate change perceived by the community at the project sites were the change in livestock production, loss of livestock, change in pasture and appearance of new diseases. Similarly, the major adaptation measures employed by the community were vaccination of animals, building proper sheds, increasing plantation and storage of fodder.

Being evidence-based, the findings from the study will help develop climate-smart livestock development plans and programmes in the country as the information obtained will be useful in mainstreaming climate change into development plans.

Context and Importance

The livestock sector, that plays a major role in the economy of Nepal, is highly sensitive to climate change. Findings from elsewhere suggest that livestock production has been affected to a great extent by climate change. (Aydinalp and Cresser, 2008; Hoffmann, 2008; Thornton, *et al.*, 2007). Climate change affects livestock productivity, which has an impact on families' livelihoods (Thorton, *et al.,* 2009). The National Adaptation Programme of Action (NAPA, 2010), which is a national document for climate change work in the country, developed in a consultative way in 2010, clearly demands the need for climate change-related work at the national level.

Studies are limited for Nepalese conditions on this endeavour. This study, therefore, proposed to understand the community perceptions of the effects of climate change on their livelihoods, identify and rank the adaptation strategies being employed, and then apply necessary and appropriate technical interventions at the sites. The study also identifies some of the likely effects of climate change on livestock production, and then discuss some of the adaptation plans that are needed to be developed or established.

Being evidence-based, the findings from the study will help develop climate-smart livestock development plans and programmes in the country as the information obtained will be useful in mainstreaming climate change into development plans, particularly livestock development plan.

[1] Himalayan College of Agriculture Science and Technology, Kathmandu

Research Findings

The average livestock holding size (33.7) was large, where sheep and goats (24.9 being average) are higher in number than others. The livestock are found being kept for multipurpose uses: milk, meat, manure and transportation. This indicates that livestock is a very important commodity for the region and a breed developed and established for single trait (milk or meat) may not be suitable for the region; rather native breeds may be more appropriate (Neopane and Devkota, 2015).

There has been significant deterioration in the rangelands as the stocking rate (number of animals grazing in the rangeland per unit area) has increased, but the productivity of rangeland has declined. The result presents increased stocking rate (2.62 LU/ha) and decreased carrying capacity (0.22 LU/ha) compared to the earlier reports (FAO, 1990, 2008). These findings were derived from both survey and action research. The findings indicate a need for proper interventions for improving the rangelands, as they are important source of fodder at the project sites.

There has been prevalence of both external and internal parasites in the region, and the rate of prevalence is increasing. Similarly, disease prevalence has been increasing, with greater occurrence of the Foot and Mouth Diseases (FMD), Haemorrhagic Septicemia (HS), Hematuria in cattle and buffaloes, while that in sheep and goats were PPR and pneumonia. Despite this, the vaccination rate was low, with the overall vaccination rate of less than 30%, ranging from 0% in Ghami to 60% in Kunjo. This clearly suggests that the vaccination programme has to be strengthened in the region.

There has been a common practice of uncontrolled mating without a strategic breeding plan at the sites, and this is aggravated by in-breeding, which is contributing to poor animal productivity. There is an utmost need for introducing proper interventions in this regard. Use of native breeds at the project sites may be a good alternative, provided the community adopts strategic selection and breeding.

The community has experienced climate change in the region. The major variables found were the timing and amount of snowfall, temperature, and the amount and intensity of rainfall. They perceived the effects of climate change on livestock production and had also adopted measures to cope with the climate change. The major effects of climate change perceived by the community at the project sites were the change in livestock production, loss of livestock, change in pasture and appearance of new diseases. Similarly, the strategies adopted by the community at the project sites were vaccination of animals, building proper sheds, increasing plantation and storage of fodder. In-depth study of the effects of climate change on livestock production and livelihoods is, however, lacking and is urgently required.

Methods

The study was carried out in Mustang district (a temperate and alpine region) in Nepal between March 2015 and August 2016. Three VDCs in Mustang, viz Ghami, Kagbeni and Kunjo, were selected based on the topography variation and livestock-rearing pattern. The study areas lie between 28° latitude and 89° longitude and are located at areas ranging from 2,500 to 4,500 masl (DADO, Mustang, 2016). In this study different methods and techniques were used to collect qualitative and quantitative data from both primary and secondary sources. Secondary data were obtained from review of both published and unpublished literature from various sources. Results of these reviews were used to support various aspects of the study. Primary data sources included structured and semi-structured interviews for household survey, KIIs and FGDs.

A household survey was conducted in three VDCs of the district to obtain information on climate change issues using questionnaires. The selection of households for baseline survey was done on random basis. A total of 250 households (100 each in Kunjo and Kagbeni and 50 in Upper Mustang) were administered the household survey. Following the household survey, FGDs, involving eight to ten persons at each site and including men, women and senior citizens, were held at the three sites to capture the required information. The key informants were district officials, extension workers and elderly people in the village.

Quantitative data were coded, processed and analysed using statistical R software package (R Core Team, 2015). Frequency distribution and cross-tabulation were employed to compare different variables within and across villages. Climatic data such as rainfall and temperature were analysed using Excel to generate graphs showing patterns of various aspects of climate change.

Following the identification of the strategies the community has adopted, technical interventions were proposed increasing their adaptive capacity for mitigating the effects of climate change on livestock production. The proposed interventions included several training packages, action research and support for increasing livestock production.

Recommendations

Animal health management: From survey and action research, prevalence of diseases (FMD, Hemorrhagic Septicemia and Hematuria, particularly in cattle and buffalo, and PPR in goats) was observed. Vaccination showed results in terms of protecting animals and saving income greatly as supported by the case studies in both Kunjo and Kagbeni. The vaccinations have given to the livestock owners benefits worth NRs 500 thousand (USD 5,000). However, there is no effective practice of vaccinating animals (cattle and buffalo and sheep and goats). The vaccination programme should be established by District Livestock Service Office (DLSO), Mustang, guided and steered by the Department of Livestock Services (DLS). The routine vaccination of animals for FMD and HS in cattle (including yak and *chauri*) and buffalo and PPR in goats is needed. This would enhance the community capacity to cope with the climate change effects. For ensuring regular delivery of services, DLSO should help produce local resource persons (LSPs) for providing veterinary services at the village level as the DLSO does not have enough capacity for providing services for entire district.

Animal breed management: The findings showed that there has been a common practice of adopting uncontrolled mating without a strategic breeding plan in the region. This was further aggravated with inbreeding contributing to lower animal productivity. The knowledge of inbreeding was low in the region. The results of earlier studies show that the Chyangra goats of the region (Mustang) are smaller in size than those of other locations of the country. It is suspected that inbreeding and *ad hoc* breeding plan may be the reasons for the smaller size of Chyangra goats, but this needs further investigation. This is certainly a good research agenda for the country. The research questions for the study would be: i) Are Chyangra goats of the Mustang region smaller than those of other parts of the country? And ii) Does this relate to inbreeding? Strong evidence suggests that inbreeding rate is very high in Lulu cattle, where close breeding (mating of father to daughter and mother to son) is common. These indicate that some interventions in this regard should be made urgently. The interventions could be: i) regular orientation and training to the community by DLSO, Mustang, for educating them about breeding plans and inbreeding. This was done by this project at the three sites and it was felt that this needs to be continued and owned by the DLSO; and ii) Exchange of males (bucks and bulls) at regular interval should be initiated and continued. This would check the inbreeding and improve productivity.

Animal feeding management: The findings from the study have showed that there has been a decline in the productivity of rangelands in the region. The stocking rate has increased and the productivity of the rangeland has declined. The rate of toxic and unidentified forage species has also increased in the rangelands. The findings indicated a great need for proper interventions for improving the rangeland, as they are an important source of fodder at the project sites. In order to do so, the following measures should be applied:

i) Research on the identification of suitable forage species for both rangelands and grazing lands;
ii) Introduction and evaluation of forage species for rangelands; and
iii) Integrated management of rangelands.

Climate change: The findings of the study showed that the community has experienced climate change in the region. They have perceived the effects of climate change on livestock production and have also adopted measures to cope with the impact of climate change. In-depth study of the effects of climate change on livestock production and livelihoods is, however, lacking and urgently required. In-depth study of the impact assessment and adaptation plan is very essential.

Despite the role that livestock plays in coping with the risk and providing livelihood options, there is only limited knowledge of the interactions of climate with other drivers of change in the livestock-based system on broader trends. This has to be studied comprehensively so as to develop an adaptation plan very effectively. Adaptation options need to be tested in more extreme environments.

Future Research

There are several issues that have appeared to be agendas for research in the country. Some of them could also be agenda at international level. They are as follows:

i) Evaluation of suitable forage under apple orchard. Further research and study on suitable time for sowing these forage species in Mustang District;

ii) Evaluation of suitable forage for improving rangelands, including the study of the toxic and unidentified forage under rangelands;

iii Evaluation of native breeds of livestock (Lulu cattle, Chyangra goats, Yak and Chauri, etc) for assessing the adaptability of these breeds to climate change;

iv) Disease investigation and its relationship with climate change;

v) In-depth study of climate change (investigating relationships between livestock, climate change and livelihoods);

vi) Further investigation into the impact of climate change; and

vii) Understanding the strategies in greater depth and promoting these practices

Conclusion

The livestock commodity is an important and well-established sector for the region (Mustang) as the holding size is far greater than the national average. The native breeds of livestock were found being kept by almost all households, which shows the importance of native breeds. Despite this, there is lack of in-depth knowledge of the adaptive capacity of native breeds for climate change. This needs to be investigated.

The community has been perceiving climate change and noting its effects on livestock production. They appeared to be using several measures for adapting to climate change, though measures varied from one site to another.

The community needs several interventions for increasing adaptive capacity.

Despite the role of livestock in coping with risks and providing livelihood options, there is limited knowledge of the interactions of climate with other drivers of change in the livestock-based system on broader trends. This has to be studied comprehensively so as to develop an effective adaptation plan. Adaptation options need to be tested in more extreme environments.

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VULNERABILITY OF LIVESTOCK FARMING SYSTEMS TO IMPACT OF CLIMATE CHANGE IN THE TARAI REGION OF NEPAL

Shiva Chandra Dhakal[1], Raj Kumar Adhikary[2]

Executive Summary

In the context of global climate change, the livelihoods of farming communities dependent on natural resources become more vulnerable and exposed to unpredictable weather events. This study examines the vulnerability of livestock farming communities with the objective of assessing vulnerability and factors affecting adoption of adaptation strategies. The study used the data collected from 600 households from six districts of Nepal's Terai region for the year 2015 and data were analysed primarily using the principal component analysis and logistic regression techniques. The results of the vulnerability analysis implied the focus should be on strengthening the adaptive capacity of households and communities as these have greater role in the reduction of vulnerability. Out of the study districts, Banke was found the most vulnerable and Chitwan the least vulnerable. The degree of vulnerability with more than two-thirds of the households in vulnerable categories expands as the research areas are far from the central part of the Terai region, like in Banke and Sarlahi, demanding focus on policy interventions on mass scale in such areas. The logistic regression model explains that regional variance, involvement in farmers' groups and cooperatives, size of livestock holding, access to credit, and level of education were dominantly affected by the different farm-level adaptation strategies. Policies focusing on awareness raising, infrastructure development, technological development and strengthening of social institutions are suggested to increase the adaptive capacity and reduction in vulnerability for overall well-being of farming communities.

Context and Importance

Livestock constitutes an integral part of the Nepalese farming system. In one way or the other, the farming communities in Nepal have close ties with livestock. The importance of livestock is especially higher for resource-poor farmers who treat them as an integral part of their lifestyle. But, in recent years, climate change has posed serious threats to farming communities, which is evident in the adverse effects on the crop and livestock. Especially resource-poor small-scale farmers in a developing country like ours are more vulnerable and more likely to suffer from these adversities of climate change due to their lower capacity to adapt to and fight back the adverse impacts of climate change. Vulnerability of the livestock sector and livestock farmers to the current climate change scenario needs to be assessed and appropriate adaptation strategies and policies to cope with the impacts of climate change need to be formulated and introduced to vulnerable groups. This study ultimately aims to ensure better living for the vulnerable resource-poor farmers by increasing adoption of adaptation strategies with appropriate policy interventions.

Research Findings

Most of the respondents were aware of the climate change and had noticed the increased summer temperature, increased intensity of summer rainfall, decreased duration of summer rainfall and increased duration of droughts. Regarding other parameters, the respondents perceived decreased winter temperature, increased number of hot days, decrease in the number of cold days, delayed onset of monsoon, decrease

[1] Agriculture and Forestry University, Chitwan
[2] Heifer International Nepal, Kathmandu

in the frequency of winter rainfall, and depletion of undergroundwater table. Decreased milk production and productivity, heat stress, cold injuries, and unavailability of feed and fodder were found as the major impacts of climate change on the livestock production system. The mixed farming system of different species of livestock, reduction in herd size, diversification of livestock species, feeding feed supplement to livestock, planting of fodder trees, construction of improved sheds, diversification of farm activities and mixed farming are the major adaptation strategies adopted by the farmers of the study areas. Some other measures like insurance and water harvesting for irrigation were adopted by less than one-fourth of the study households.

The results of the vulnerability analysis implied that adaptive capacity had a major role to play in the determination of vulnerability. The biophysical elements determining vulnerability under the category of sensitivity and exposure are not under the control of policymakers and thus focus should be on strengthening the adaptive capacity of households and communities. Among study districts, Banke was found the most vulnerable and Chitwan the least vulnerable. Furthermore, about two-thirds of all study households belonged to moderate to high vulnerability groups, which indicates the mass approach for the extension of adaptive capacity.

The logistic regression model explained that, out of the fourteen different factors considered in the central region, involvement in farmers' groups and cooperatives, size of livestock holding, access to credit, level of education, and the number of family members with above secondary level of education affected the adoption of major adaptation strategies like improved shed, fodder cultivation, enhanced access to extension services, improved breed, etc. Those who did not adopt any strategy mentioned lack of information on adaptation methods and financial constraints on using any of the adaptation methods.

Methods

The study was conducted in six districts in the Terai region of Nepal, namely Morang, Sarlahi, Bara, Chitwan, Rupendehi and Banke, stretching from east to west. Two VDCs were selected from each of the selected districts and fifty households were randomly selected from each VDC to obtain a total sample size of 600. Primary data was collected using interview schedule and checklist administered through face-to-face interview, KII and FGD. Secondary data were collected from different publications of organizations working in the agriculture, livestock and climate sectors. Collected data were entered into SPSS and analysed, using STATA to apply analytical tools like trend analysis, problem confrontation index, adoption strategy index, principal component analysis and logistic regression technique. The trends of change in climatic variables like temperature and rainfall were assessed, using simple regression techniques. Vulnerability assessment was accomplished using integrated vulnerability approach with the incorporation of the weight obtained from the principal component analysis of the indicators categorized into adaptive capacity, exposure and sensitivity. Factors affecting adoption of major adaptation strategies were studied, using logistic regression techniques, considering adoption as a function of different personal, social, economic, technical and institutional factors.

Recommendations

Based on the research findings, the following recommendations are made for policy formulation and implementation:

- Location- and group-specific adaptive capacity and adaptation strategies are to be prioritized for implementation, like focusing more on western and eastern Terai and ethnic communities.
- Policy measures should be in place for the arrangement of activities like provision of post-disaster relief measures, establishment of early warning systems, creation of opportunities for non-farm livelihood options, infrastructure development and promotion focusing on all-weather roads, river barricade construction, irrigation, along with education and training of farmers for increasing their adaptive capacity.
- Micro-level adaptation options (farm production adjustments such as diversification and intensification of crop and livestock production; changing land use and irrigation) are to be promoted.
- Institutional and policy adjustments (arrangements of subsidies and insurance, income stabilization options, cost-based pricing policy) are suggested.
- Income-related adjustments (insurance schemes, credit schemes, income diversification opportunities, employment shift from farm to off-farm, commercialization) are recommended.
- Technological developments (development and promotion of new disease-resistant and heat-

tolerant livestock breeds, crossbreed generation and improved animal health technology) are to be generated and extended.

- Invest in research and communication to improve understanding of the complex relationship between livestock and climate change.
- Strengthen human capital through general basic education and other forms of public awareness, training, etc, and make information on adaptation options widely available to all stakeholders, and particularly to livestock farmers, in order to strengthen their capacity to make choices over adaptation strategies.
- Introduction of awareness and other support activities through dairy cooperatives and groups.
- For conservation and sustainable use of surface and undergroundwater sources 3R (Retention, Recharge and Reuse) techniques are to be extended.

Besides these policy recommendations, the following suggestions are made for farmers with special focus on increasing the adaptive capacity to reduce vulnerability:

- Farmers should join farmer groups and cooperatives so that they can gain easy access to information and credit, which will make them capable of making wise decisions.
- Proper ventilation regimes, provision of shed and shift in feeding time to afternoon help to reduce thermal effects on livestock.
- Establish and use community-based breeding, storage, processing and pasture management facilities.
- Farmers who are literate are easier to convince than illiterate farmers about adoption of innovation. Hence, farmers should join school, college, university and training programmes, whichever is possible according to their economic status and educational background.
- Exposure visit of farmer groups to commercial pockets of livestock production should be organized for increasing their knowledge and skills of adoption of different adaptation strategies.
- Increasing extension services, promoting insurance schemes, establishing and maintaining grazing land in community-owned land, planting fodder and forages, diversifying livestock species even on commercial scale increase adaptive capacity.

Future Research

- Research on quantification of economic losses by different climatic hazards and climate change impacts on dairy farming;
- Research on the economic analysis of the different adaptation strategies practised by farmers and recommendation of the best least cost adaptation strategies in a particular community;
- Modelling of livestock system productivity to the different climate change scenarios;
- Research on farmers' psychological and behavioural manner with respect to adoption of adaptation strategies;
- Vulnerability analysis of mid hills and high hill areas of livestock production system to climate change impact; and
- Use of advanced software to generate hydrological and meteorological data at village and household level for vulnerability study and allied climate change study.

Conclusion

The Terai region of Nepal, which is a potential pocket area for dairy farming, despite being one of the most accessible regions in the country, is highly vulnerable to climate change. The degree of vulnerability is higher in the western and eastern Terai as compared to the central Terai. It is recommended that the adaptive capacity of farmers be increased by enhancing their social, technological and institutional strengths of farming households. The proposed change would not require more legislative policy changes, but necessitate a change in the governance culture towards effective implementation of existing policies, especially targeting the more vulnerable communities. Our results point to the need for further research focusing on in-depth assessment of climate change impact, economic assessment of adaptation strategies and vulnerability, covering the different agro-climatic and geographical regions of the country.

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AGRICULTURAL CALENDAR SHIFT DUE TO CLIMATIC CONDITIONS IN THREE ECOLOGICAL REGIONS OF SAGARMATHA ZONE, NEPAL

Bed Mani Dahal[1], Rabindra Kayastha[1], Chhatra Mani Sharma[1], Smriti Gurung[1], Nani Raut[1], Ahuti Shrestha[1], Bibhu Gautam[1]

Executive Summary

The farmers of Nepal have also experienced changes in climatic variables associated with climate change. Change in seasonal calendar is an important coping option to keep the production system intact even under climate change conditions. The practices of adopting these options were, however, undocumented. Hence, the study was proposed to investigate the impacts of climate change on seasonal calendar and agricultural production system.

The main objectives of the research were to study the climate change scenario, to identify the historical agricultural calendar and change in agricultural cultivation time (if any), to establish linkages between agricultural calendar change and agricultural production for major crops, and to document the adaptation strategies in the study area. Tingla VDC of Solukhumbu (Mountain region), Prapcha VDC of Okhaldhunga (Hill region) and Hanuman Nagar VDC of Saptari (Terai region) were selected for the study.

First, the meteorological data from each study district were compiled and computed to find the trends of temperature, rainfall, and humidity change. The agricultural calendar for crop cultivation, weeding, ripening, harvesting for major crops was documented. The data obtained from key informant interviews (KIIs), focus group discussions (FGDs) and direct observations were assessed for historical and current agricultural calendars, as well as adaptation strategies adopted by the farmers. Based on rainfall, temperature and humidity data of the past thirty years, the research found that climate change is happening and no impact has yet occurred on agricultural calendar change, except for a slight shift in Okhaldhunga. Similarly, the effects of climate change on agricultural production and adaptive measures for agricultural productivity were identified for different ecological regions. Intensive and regular monitoring of the climatic variables and agricultural practices in the study areas are recommended for revision of agricultural policy.

Context and Importance

Nepal, in spite of being an agricultural country, where agriculture provides employment for nearly 66% of the population and contributes nearly 33% to the GDP, currently faces an alarming challenge in food insecurity, with approximately 3.5 million people still food insecure (CBS 2011). Traditional farming practices are unable to meet the needs of the people, and this can be achieved only through sustainable agriculture intensification. The problem of food insecurity is further exacerbated by the impacts of climate change. Therefore, there is an urgent need to address the impacts of climate change through enabling policies and programmes.

In the Nepalese context, the root causes of food insecurity are (i) the physiography of the country, with remote and inaccessible areas; (ii) natural hazards like Glacier Lake Outburst Flood (GLOF) events, landslides, flood and erosions limiting food production; (iii) traditional methods of food production, which is not sufficient to meet the needs of the population; (iv) low awareness of farmers; (v) lack of technical and economic infrastructures, and so on. Sometimes, these problems are aggravated by political instability. Apart from these, some policies and practices initiated by the GoN have also not been successful. Therefore, there is an urgent need for formulating and implementing new policies and programmes.

[1] Department of Environmental Science and Engineering, Kathmandu University

Government policies and programmes such as the Agriculture Perspective Plan (APP, 1995) and the National Agricultural Policy (NAP, 2005) aim to increase food production to reduce food insecurity. These policies lack strategies for combating climate change impacts; as a result, it is important to formulate, introduce and implement new policies. Limited efforts have been made in the past to understand the impacts of climate change on agriculture and to design adaptation and mitigation policies and programmes.

Research Findings

The main research findings are as follows:

- There is a trend of increasing temperature in the studied areas and local communities are aware of the days becoming hotter in recent years.
- Monsoon arrival time has been delayed.
- Although the bulk of precipitation occurs during the monsoon, erratic rainfall patterns are becoming common, particularly in the last five to seven years.
- Agricultural production has increased as farmers are adopting agricultural intensification such as using high-yield varieties of crop, increased irrigation, cultivation of early ripening varieties, use of pesticides and chemical fertilizers to increase yield, cultivation of cash crops, etc.
- No distinct agriculture calendar shift was observed, but agriculture calendar was obtained and a shift in the time of rice planting was reported from Prapcha VDC of Okhaldhunga district. Similar events were, however, also reported from other districts where floods, droughts, pests and diseases affected agriculture performance and calendar.

The policies that could address the issues and concerns of the people are:

- Communities are aware of the change in temperature but unaware of the long-term impact on them or their environment. Hence, awareness of climate change adaption mechanisms is necessary.
- Agricultural intensification needs to be practised in a sustainable manner and necessary crop varieties, fertilizers, irrigation facilities and market access are important to contribute to agriculture performance.
- Climatic factors are important for early decision-making for farmers and general people; hence, setting up of more meteorological stations, as well as ensuring prompt and regular weather reporting, is suggested.

Methods

The study was carried out in three districts of Sagarmatha zone, representing three ecological zones: Solukhumbu (Mountain region), Okhaldhunga (Hill region) and Saptari (Terai region). Because of time and financial limitations, only one VDC was selected in each district: Tingla in Solukhumbu, Prapcha in Okhaldhunga and Hanuman Nagar in Saptari district. The primary data, ie information on agricultural calendar shift, linkage between agricultural productivity and climate change, and perception of, and adaptation to, climate change, were collected in the field. The meteorological data were collected from the Department of Hydrology and Meteorology. The main climatic parameters used in this study were temperature, rainfall, and humidity data from the year 1980 to 2013. The trend of temperature (mean maximum and mean minimum) and rainfall (yearly total, seasonal and abnormal conditions) were analysed and presented in graphical form. The meteorological data were used to check the trend of climate change in the study area.

Agricultural data and farmers' perceptions of climate change were collected through baseline survey, group discussions and KIIs. The study team visited each study site, viz Hanuman Nagar, Prapcha and Tingla VDCs, to gather agricultural data. Structured open-ended questionnaire was developed to study the different aspects of agricultural calendar shift and climate change in the area. Based on the total number of households in the VDCs (based on the national census of 2011), at least 10% of the households from each VDC were randomly selected for the questionnaire survey. The total number of households included in the survey was 95 from Hanuman Nagar and 100 each from Prapcha and Tingla VDCs. The household selection was done purposively to include the same ratio from all the wards of the VDCs.

FGDs consisted of twenty to thirty participants from each study site. The participants of group discussions were selected based on who played prominent roles in agricultural activities in the area. The participants were mainly farmers and permanent residents of the VDCs. The discussions mainly focused on the different aspects of agricultural activities, trend of agricultural cultivation, agro inputs, crop productivity and climatic effects on agro-products. Similarly, the perceptions of the changes in crop production and climate change were documented. A total of ten key informants, three to four key informants from each study VDCs, were identified during the FGDs and were interviewed separately. The KIIs were mainly focused on the cultivation dates and calendars of different crops, use of fertilizers, crop production, weather variables, etc. Climate change adaptation measures adopted by farmers were also documented during the field visits. The data collected were computed, statistically analysed and presented in graphs, tables and statistical forms like average, mean, maximum, minimum, variance, regression, etc.

Recommendations

The national agricultural plan and policy should take into account the linkages between priority agricultural programmes and variability in climate. This study found that the farmers experienced changes in rainfall pattern and temperature, which are in line with the recorded climatic data. Therefore, the policy should focus on the grass roots level to make the farmers aware of the possible impacts of climate change on production and adaptation:

- Promote awareness campaigns on the impacts of climate change on agriculture at the grass roots and higher levels;
- Develop and disseminate new crop varieties and production technologies to address climate change, as well as for increased production, income and food security;
- Promote participatory research and development, and increased access to modern technologies and services; and
- Support development of required infrastructure (roads, irrigation, electricity) and development institutions and projects to work in an integrated approach for sustainable impacts and output.

Future Research

The future research should focus on increasing the coverage of the study area in order to represent the entire zone for more comprehensive endeavours. The future research should also be extended to other agro-ecological regions of the country in order to find the impact of climate change on agriculture and livelihoods of the people. Focus should be put more on the detailed activities of each major crop and their timing over a period of time for generating data on agricultural calendar shift in Nepal.

Conclusion

This research was conducted to study the linkage between climatic variables and agricultural productivity and how these factors have changed in the last three decades in different ecological zones, viz the Terai (Saptari district), the hills (Okhaldhunga district) and the mountains (Solukhumbu district) in the Sagarmatha Zone. Temperature and precipitation data of the past three decades also indicated changes in their trends. Fluctuations in precipitation pattern were observed in Saptari and Okhaldhunga, particularly during non-monsoon periods. Most of the participants and informants agreed that the monsoon arrival time had changed and days were hotter in recent years. Cereal crops were the major crops grown in the regions, with rice as the main crop in Saptari and Okhaldhunga, while maize was the primary cereal crop in Solukhumbu. Potato, initially introduced as a vegetable crop, has now become another major crop along with maize in Tingla, Solukhumbu. Furthermore, vegetables and potato were introduced later as commercial crops. The study also showed increased incidence of pest infestations in the crops, particularly during summer. Average crop production differed significantly for major crops with increase in production. The different adaptation measures the farmers had adopted are replanting of trees, change in crop varieties such as cultivation of early ripening and high-yielding varieties. The farmers attributed increased crop production to improved agricultural technology, high-yielding crop varieties, pesticide use and irrigation. Low yields due to erratic rainfall patterns and increase in the incidence of pests and diseases were also reported. Although agriculture calendar shift was not practised by the farmers, occasional calendar shift in rice was observed in Okhaldhunga. Enabling policy and programme interventions are urgently needed to address the impacts of, and vulnerability to, climate change on agriculture production, natural resources and livelihoods of people in the diverse agro-ecological regions.

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UNDERSTANDING CLIMATE CHANGE ADAPTATION BY FARMERS IN CROP PRODUCTION IN NEPAL

Madhav Dhital[1], Hridesh Sharma[1], Min Raj Bhandari[2]

Executive Summary

Agriculture, which employs about 67.5% of the workforce and contributes 31% of GDP, is the mainstay of Nepal's economy. Only about 25% of the total area of the country is cultivable, another 33% is forested and the rest is mostly mountainous. The mountains are experiencing rapid snow melting, while the Terai faces prolonged droughts. Nepal is prone to a variety of recurring climate-induced risks such as floods, droughts, hailstorms, glacial lake outburst floods (GLOFs), and heat and cold waves. Poor, disadvantaged and excluded groups living in rural areas are usually the hardest hit by these natural disasters. Agriculture, the principal economic sector, is highly exposed and most vulnerable to these extreme climate events. Global climate change constitutes an additional threat to the already deprived rural population heavily engaged in agriculture. The climate change projections indicate that the main impacts are likely to include significant warming and uneven and erratic distribution of precipitation, leading to increased frequency of extreme weather and climate events, including floods and droughts. The impacts of climate change and related extreme events made life of marginalized and poor difficult. The rural poor, disadvantaged and excluded groups of population are least able to adapt because they lack resources to undertake new activities. Rural communities face increased risks, including recurrent crop failure. Changing temperature and weather patterns further create conditions for emergence of new crop varieties that increase the crop yield or income level of farmers.

[1] Agriculture and Forest University, Chitwan
[2] MADE Nepal Chitwan

Context and Importance

Climate change has brought about changes in the farming systems in the mountains, hills and Terai of Nepal. The impact of climate change and related extreme events has made the life of marginalized and poor difficult. A key challenge for decision-makers, policymakers, and development partners is to understand the strategies adopted by farmers and other stakeholders to address the climate change-induced stress in agriculture. Smallholder farmers are the most vulnerable to climate change and they have no alternative but to adapt their livelihood systems to the changing climatic conditions. Fortunately, several practical options of adaptation exist.

Although farming communities are already using several coping strategies to manage climate risks like changing crops, diversifying enterprises and rainwater harvesting, these existing coping strategies are insufficient in managing the current risks of climate vulnerability and climate change and serving the vast number of people facing climate-related uncertainties and impacts. The rural poor, disadvantaged and excluded groups of population are the least able to adapt, because they lack resources to undertake new activities. Losses and damage resulting from climate risks are attributed to insufficient public awareness, lack of, or inadequate, preparedness, lack of proactive risk management practices, low level of technical expertise and skills in adaptation to climate change, and lack of reliable data and information, all of which enhance the vulnerability of agriculture-dependent livelihood activities to climate risks. There is no doubt that, in Nepal, food scarcity/insecurity has been a major problem and a recurrent phenomenon, which has been escalated by climate change impacts and the country has low level of adaptation strategies against climate change impacts.

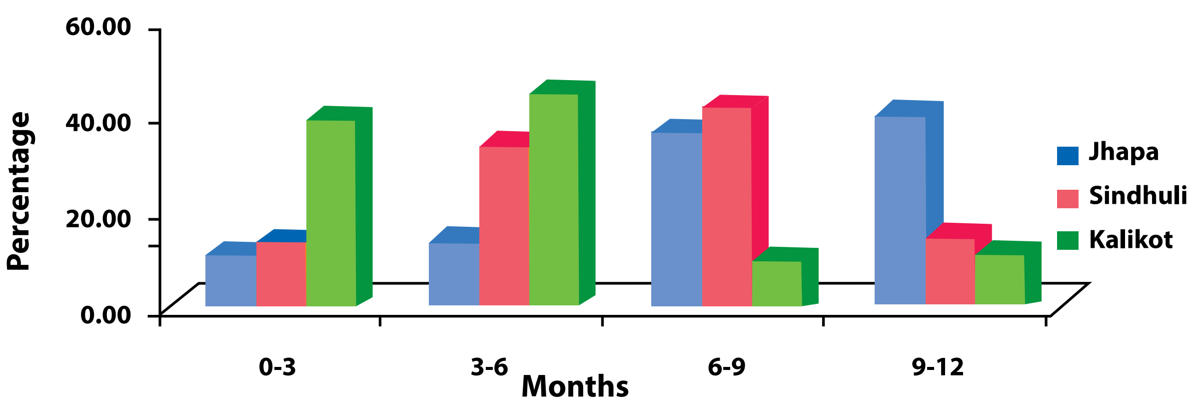


Figure: Food Secuity situation

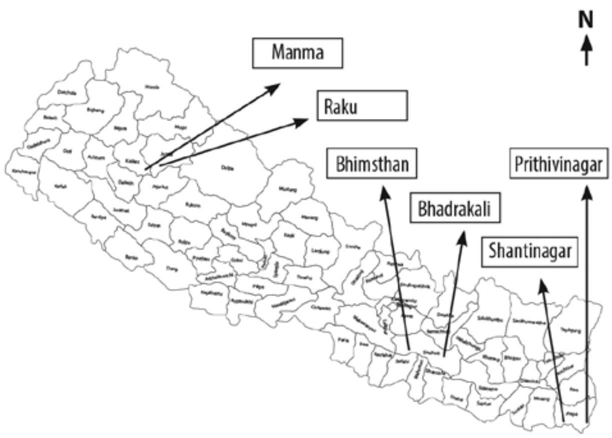
Research Findings

This study was conducted in Jhapa (Terai), Sindhuli (Hill) and Kalikot (Mountain) districts of Nepal from February 2015 to April-end 2016 to assess the understanding of climate change adaptation by the farmers in crop varieties. The majority of respondents perceived the effects of the climatic factors on the cropping pattern. There is a shift in nursery bed preparation/seed sowing time in rice, wheat, maize and millet over the period of ten years. In cereals, legumes and vegetables, the major climatic factor for loss is drought experienced by majority of respondents. The trend analysis of three districts by Mann-Kendall test, maximum temperature ($p< 0.05$), average temperature ($p< 0.05$) and rainfall ($p< 0.05$) from 1989 to 2013 have shown significant trends, where maximum temperature ($S= 0.407$) and average temperature ($S= 0.362$) show positive trends, while rainfall ($S= -0.5$) shows a negative trend. The impact analysis of rice suggests that, in Jhapa, rainfall and relative humidity have significant relation to rice yield at 5% confident level and 10% confident level. Rainfall has a negative effect, while relative humidity has a positive effect on rice yield. Similarly, in Kalikot, rainfall has significant and positive relation to rice yield at 10% confident level. The results also suggest that, in wheat, maximum temperature has a significant and positive relation to wheat yield at 10% confident level in Jhapa. Majority of respondents in Jhapa and Sindhuli have adopted new varieties in place of old varieties. The adaptation of new crop varieties experienced by the majority of the respondents is for greater yield, which was followed by resistance to the disease and pest and change in income.

Farmers have adopted improved varieties, which have higher productivity to meet the increasing demand for food. Among the various reasons for the adaptation of new varieties in cereals, vegetables, fruit and legumes are for the greater yield, followed by resistance to diseases and pests and change in income. Varietal richness was found high in Jhapa, followed by Sindhuli and Kalikot in that order. On the measures of adaptation to climate change, change in crop was found to be adopted by the majority of the respondents in Jhapa and Sindhuli. In agriculture, use of short duration varieties, use of hybrid and quitting agriculture were preferred in Jhapa, Sindhuli and Kalikot simultaneously.

Methods

The research project was carried out in Shanti Nagar and Prithivi Nagar VDCs of Jhapa district, Bhimsthan and Bhadrakali VDCs of Sindhuli and Manma and Raku VDCs in Kalikot district of Nepal. Food security was assessed by indexing. Indexing was used to calculate the food sufficiency index, index for coping strategies and problems associated and reasons for food security analysis. Impact of climate change in rice, maize and wheat was assessed by the linear regression data model. The adaptation strategies related to crop varieties were

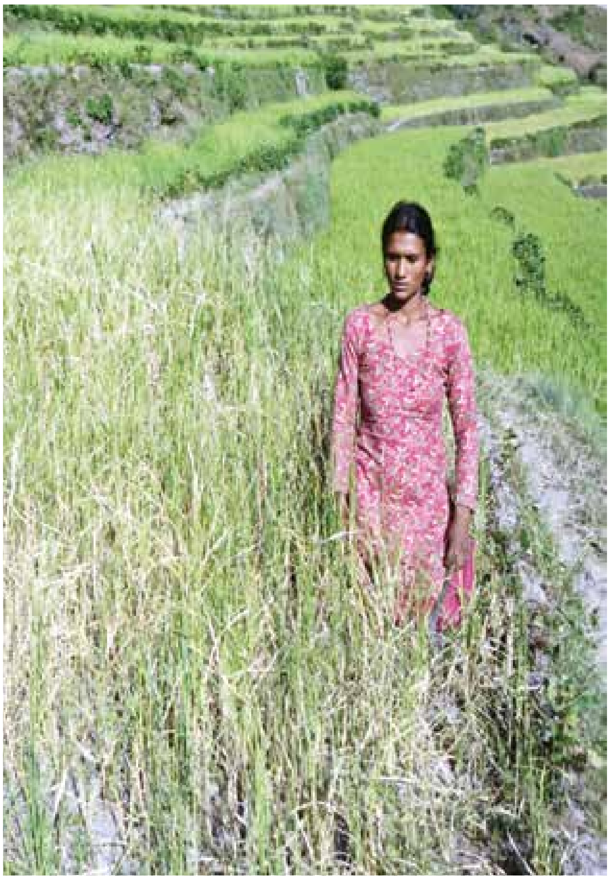


analysed by listing the crop varieties used in the past and present. The varietal characteristics under climatic change scenario were critically analysed by using the time series data of climatic variables (eg rainfall and temperature) and the crop yields and production for available years taken from different secondary sources.

Recommendations

Diverse Geography

Nepal's geography is divided into three distinct geographic areas: Mountains, Hills and the Terai. Each region has unique biophysical and socioeconomic characteristics that vary significantly from one another. Such rich diversity within a relatively small area makes it difficult to distinguish the patterns related to climate change. Therefore, location-specific approaches are necessary for the adaptation strategies to be successful.



Impact of climate change on crops

The results suggest that, in rice, the model ranging from 40% to 15% explains the variation in the rice yields in the three districts. In Jhapa, rainfall and relative humidity have significant relation to the rice yield at 5% confident level and 10% confident level simultaneously. Rainfall has a negative effect on the rice yield, while relative humidity has a positive effect. Maximum temperature and minimum temperature could not influence the rice yield. Similarly, in Kalikot rainfall has a significant and positive relation to the rice yield at 10% confident level, while other climatic variables could not influence the rice yield.

The results suggest that, in wheat, the model ranging from 40% to 9% explains the variations in the wheat yield in the three districts. In Jhapa, maximum temperature has a significant and positive relation to the wheat yield at 10% confident level. In addition, in Sindhuli, relative humidity has a significant and negative relation to the wheat yield at 5% confident level, while climatic variable could not influence the wheat yield in Kalikot.

The results suggest that, in maize, the model ranging from 47% to 7% explains the variation in the wheat yield in the three districts. In Jhapa, maximum and minimum temperatures have significant and positive relation at 5% confident level and 10% confident level, whereas, in Sindhuli, maximum temperature has significant and positive relation to the maize yield at 5% confident level.

Adoption strategy

Biodiversity loss is occurring and is expected to continue if the effects of climate change intensify. Since different crops are suitable to specific ecosystems, changes in soil, temperature, humidity, sunshine and water availability alter particular species' ability to survive in its environment. Modern and hybrid seed varieties are increasingly replacing local traditional varieties as they often provide greater drought resistance or higher yields or change the income level.

As rising temperatures and the effects of climate change are felt more intensely, food insecurity in Nepal is expected to become more acute. Heavy reliance on rainfed farming, limited irrigation facilities, and lack of water conservation and harvesting practices mean that extreme events can prove disastrous for agricultural output. Furthermore, rising temperatures have significant impact on the moisture and nutrient level of soil through rapid evapo-transpiration, soil erosion and landslides.

Crop performance

In the context of change in crop performance, changes were noticed in the crop yield and in the decreasing trend. Climate change has affected crop performance in a negative way. This study recommends that future agricultural research should focus on the development of high temperature-tolerant crop varieties. The study also recommends that a more comprehensive assessment (or field experiment) that factors in the missing weather and economic variables should be carried out to help improve understanding of the impact of climate change on crop yields.

Future Research

The current widespread food shortage problem in Nepal must be addressed immediately. Every effort must be made to ensure that the areas affected by recent drought are able to take advantage of the next planting seasons through improved access to required agricultural inputs, combined with relevant training support designed to meet the needs of farmers, particularly women farmers. Upcoming research should focus on developing climate-resilient crop varieties. Programmes should focus on contributing to agricultural productivity such as access to irrigation systems, management of climate-smart varieties, disease and pest management, etc. As the climate change impacts and adaptation are location-specific, interventions at the local level require introduction and demonstration of innovative adaptation options through a guided learning-by-doing process at district and VDC levels.

Conclusion

In a country like Nepal, where most of the rural people live below poverty line and agriculture has the major share in the country's GDP, sensitivity to changes in climate is more pronounced. Thus, adaptation plays a vital role in sustaining the livelihood of those resource poor and marginalized farmers. In the context of food security, Jhapa seems to be more secure, followed by Sindhuli and Kalikot. Increase in temperature, lack of uniformity in the intensity and amount of rainfall, increase in the frequency and duration of droughts, decrease in the amount of snowfall in recent years compared to the previous years were observed. Loss of crops is occurring due to climatic factors such as to droughts, heavy rainfall, hailstorm, frost and others. In cereals, legumes and vegetables major climatic factor for loss is drought. There is a shift in nursery bed preparation/seed sowing time in rice, wheat, maize and millet nearly by one month in recent years. There is change in the crop yield and the decreasing trend. Climate change has affected crop performance in a negative way. Farmers have adopted improved varieties, which have higher productivity to meet the increasing demand for food. Among various reasons for the adaptation of new varieties in cereals, vegetables, fruit and legumes is for greater yield, followed by resistance to diseases and pests and change in income level.

IMPACT OF CLIMATE CHANGE ON CEREAL CROP PRODUCTION AND FOOD SECURITY: A CASE STUDY OF DHADING DISTRICT, NEPAL

Surya Mani Dhungana[1], Jay Prakash Dutta[1]

Executive Summary

This study was conducted to assess the impact of climate change on cereal crop production and food security in five villages in Dhading district of Nepal. Primary information was collected from a sample of over 100 households, while meteorological and crop production data were collected from secondary sources. Descriptive analysis and econometric models were used to estimate the impact of climate change on crop production. The major constraint in the study area was the lack of irrigation facilities. More than 84% of the households lacked access to irrigation. There were occasional visits by agricultural technicians, and many of the respondents were aware of climate change and its consequences. More than 75% of the interviewees said that they noticed increase in temperature and decreasing trend of rainfall. Trend analysis showed that the maximum temperature was increasing by 0.012°C/year. Furthermore, the annual rainfall had decreased by 1.68mm/year. Its consequence was reflected in cereal crop production, which was reported decreasing during the last twenty years. The impact further deteriorated food security. The locals said that they had been facing increased food unavailability. In the past, the percentage of families having sufficient food for the whole year was 38.8; this decreased to 32.2 in recent years. Similarly, the percentage of families having food sufficiency for 11 months decreased from 14 to 11.4 and that for eight months from 27.4 to 25.6. In coping with the problem, the most common strategies were changing crop varieties (74.4%), followed by greater use of fertilizer (71.8%) and shifting the planting time (56.85%). The logit regression analysis showed that ten out of fifteen variables were statistically significant for adopting adaptation strategies. They were year of schooling of household, gender of household head, family type, ethnicity, irrigation facility, credit training of farming, knowledge of climate change, LSU and household income. Quantification of economic loss by climate change and economic analysis of adaptation practices are equally important to bring resilience programmes in support of small farmholders.

Context and Importance

Lack of scientific knowledge of climate change and its impacts on the farming system is threatening the livelihood of farming communities in the mid hills and high mountains in Nepal. Weak institutional support to these people to cope with the impact is making them more vulnerable. The majority of the farmers depend on the monsoon rain for crop cultivation. So, any change in the rainfall pattern would bring about adverse impact on their lives. The rising temperature, variations in summer and winter temperatures, erratic and higher intensity of rainfall all have contributed negatively to agricultural productivity. Similarly, farmers are unable to plant crops at appropriate time, which lowers production and increases food deficit in the country. The IPCC Climate Change Assessment (2007) stresses that most of the research on agriculture and climate change focuses on the impacts of climate change on crop production, but the broader issue of food insecurity is not linked with it. The issue of food security is directly or indirectly related to climate change impacts and coping capacity of farmers, mainly in least developed countries like Nepal. This study has attempted to link the lower production and lower access to food resulting from climate change. The study prioritizes the potential impacts

[1] Agriculture and Forestry University, Chitwan

and identifies the effective adaptation strategies to cope with the adverse impacts of climate change for securing access to food at farmers' level. Identifying the impacts of climate change experienced by farmers could help in their capacity building to cope with the impacts, which will ensure sustainability of agriculture and prepare the farming community in alternative agriculture to tackle the emerging problem of food security.

Research Findings

The major occupation of the households in the study area was found agriculture (78.2%), which complies with the national scenario. The study found that more than 66% of the households were male-headed, indicating that household decisions such as farming activities and adaptation of climatic hazards strategy were being highly influenced by men. Nearly 66% of the households were nuclear type. The average land holding per household in the study area was about 0.6 hectares, with average livestock standard unit of 19.25. The major constraint of the communities was lack of irrigation facility. Only 16% of the households had access to irrigation facilities. This is also a major problem in other mountain regions of Nepal.

On the climate change issues, only 54% of the respondents were found to be aware of climate change and its consequences. In Salyantar and Dhuwakot, the respondents had less knowledge of climate change. However, when asked about the temperature and rainfall patterns, nearly 90% of the respondents said that they felt increase of summer day temperature and about 50% reported decrease in the number of cold days in the winter. Similarly, nearly 70% of the respondents said that they were having less rainfall in both duration and frequency, noting dry spells in recent years. In conformity with the people's perception, the 20-year temperature data as available from the nearby Dhunebesi station revealed that the maximum temperature was increasing by 0.012°C per year, whereas both minimum and average temperature was decreasing by 0.036°C per year and 0.012°C per year respectively. Similarly, analysis of rainfall data of last thirteen years (2001–2014) of the station showed an irregular pattern of rainfall and decrease by 1.68mm.

The respondents reported decrease in the production of the three popular crops, viz rice, maize and wheat: 66% reported decrease in rice, 68% decrease in wheat and 48% said decrease in wheat. The respondents also mentioned that there was serious impact on crop production, crop failure, outbreak of diseases and pests. Other impacts mentioned by the local people were: decrease in the size, maturity and taste of grain. The study also found that there was a gradual decrease in the area of cultivation; for example, the area of maize cultivation decreased by 360.6 ha in the last thirteen years. The study considered various predictors to determine the impact of climate variability on maize productivity; viz seasonal maximum temperature, seasonal minimum temperature, seasonal rainfall and cultivated area. Among these, none were statistically significant; however, the area and temperature parameters presented positive impact on maize productivity, which increased exponentially by 1.442 and 2.879 respectively. Thus, these kinds of result need to be analysed further to determine the impact of climate change on production.

The study also found that food availability was also deteriorating in recent years; for instance, families with round-the-year sufficiency decreased from 38.8 to 32.2, and those with 8-month sufficiency decreased from 27.4 to 25.6. In coping with their problems, the local people of the study sites had adopted some measure of autonomous adaptation and/or mitigation strategies. The most popular strategy was the use of new crop varieties, as reported by 74.4% of the respondents, followed by intensive use of fertilizer (71.8%) and change in planting times (56.85%). Only one household was found to have crop insurance.

Methods

Research was conducted in five village development committees (VDCs) in the mountainous region of Dhading district of Nepal, viz Nilkantha, Shankosh, Muralibhanjyang, Dhuwakot and Salyantar. Both quantitative and qualitative data were collected from primary household survey and secondary information of cereal crop production, productivity, and temperature and rainfall data from the nearest station Dhunebesi by courtesy of Department of Hydrology and Meteorology. Semi-structured household survey, focus group discussion (FGD) and key informant interview (KII) were conducted to collect primary data. Climatic data of temperature and rainfall were available only for twenty years.

From each VDC, a total of 100 households were taken, thus, making a total of 500 from the five VDCs. Respondents included people over 30-year old staying in the area for at least ten years. Preliminary field visits and pre-testing of questionnaire were also conducted. Nine FGDs were conducted in each VDC, making a total of 90 FGDs. Data entry and analysis were done by using computer software packages, Statistical Package for Social Science (SPSS 16 version), STATA 9 and Microsoft Excel. Descriptive analysis was done during data analysis and reporting. Furthermore, econometric models were used to gauge the real impact of climate change on cereal crop production and their adaptive capacity and coping strategies. The log linear regression analysis was done to study the effects of precipitation and temperature on productivity of major cereal crops (rice, maize and wheat), and logistic regression model was used to identify farmers' adaptive capacity and coping strategies in relation to climate change.

Recommendations

- Develop programmes to support the farmers to increase their access to year-round irrigation facilities considering the declining wetlands so that agricultural production can be increased.
- Provide training and extension facilities to the farmers about the several improved farming practices and appropriate technology to combat the negative impacts of climate change.
- Support farmers in obtaining agricultural inputs such as drought-tolerant varieties, fertilizers, etc in right quality and quantity and in time. Furthermore, support in the development of water harvesting system for irrigation purpose was an important issue.
- Promote training programmes for improvement of income generation and livelihoods of marginal and resource-poor farmers.
- Make efforts for provision of crop and livestock insurance in the case of failure of crops and livestock. Similarly, credit and crop and livestock insurance should be provided to cope with the negative consequences of climate change.
- Develop short duration and drought-responsive varieties well adapted to the plain area. Develop insect-, disease- and weed-resistant varieties well adapted to the plain areas, along with integrated disease, pest and weed management practices.
- Forecast weather/climatic conditions well in advance of the crop planting time.

Future Research

- In-depth study of the impact of climate change in agricultural production, productivity (including livestock and availability of fish population) should be carried out in similar conditions.
- In-depth study of the impact of climate change in the livelihood of marginal farmers and their vulnerability to climate change by using several tools of participatory vulnerability assessment (PVA) be expanded in other villages.
- Quantification of economic loss by different climatic hazards and climate change impacts and economic analysis of the different adaptation strategies practised by farmers and recommendation of best adaptation strategies in that community are suggested.
- Further study should be done to develop an efficient irrigation system, weather forecasting system and appropriate agricultural technologies to minimize the negative impacts of climate change at different locations and different climatic conditions.

Conclusion

Most of the farmers perceived that the change in climate was in terms of change in the rainfall pattern, duration, timing, intensity, onset of monsoon and change in summer and winter temperatures in terms of hotness and coldness. There were visible changes in the farming system and departure from conventional farming practices. The monsoon rain was decreasing and farm becoming drier year after year. Due to the lack of timely rainfall and assured irrigation facilities, the productivity trend was declining and farmers get less benefit from farming activities. So, there should be provision of irrigation facilities either from river or from underground sources and improved farming system to boost production. Farmers should be aware of the climate change to promote them to practise improved farming packages. Farmers were practising different coping and adaptation strategies in their farm based upon their experience to tackle the changing climate, but it is equally important to plan sustainable adaptation strategies and prepare farmers to tackle the emerging impacts of climate change in forthcoming days. There should be promotion of local and indigenous adaptation practices, followed by farmers with the use of local skills and resources.

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DEVELOPMENT OF DESIGN GUIDELINES OF DIGESTERS FOR BIOGAS GENERATION AT HIGH ALTITUDE

Manchan Tiwari[1], Anuraj Rijal[1], Bhagawan Ratna Kansakar[2]

Executive Summary

The purpose of this research project is to study the methane-producing potential of psychrophilic methanogens found in sediments of lakes and swamps located at high altitude. Biogas is a proven and widely used renewable energy, which has been contributing environmental as well as social benefits. However, one limitation of technology is that it has only been effective in mesophilic temperature range. This research focused on study of biogas production potential in psychrophilic temperature range. Evidence of increased biogas potential with the use of psychrophilic methanogens is found in various research works. The psychrophilic methanogens are found in permafrost sediments/lake bottom of high altitude lakes where the temperature is low. Samples were collected from such sites, namely Gangapurna Lake, different lakes in Manang, Gokyo Lake, sites in Solukhumbu district. The samples were analysed in a laboratory for confirmation of presence of psychrophilic methanogens. The laboratory results were inconclusive. Thirteen different prototype biogas digesters of known volume were formed. The collected samples were used in the prototype biogas digesters with various amounts of organic feed. The digester was also tested after adding only organic waste for comparative study. Three digesters were kept at room temperature (mesophilic temperature range). The digesters so formed were kept at 5 and 10° celsius. Of the 13 digesters, three were without any added sample, whereas the remaining 10 digesters were incorporated with samples from various sites. The pressure reading and temperature of the samples were noted. After 55 days, the gas pressure and gas composition were tested. The results showed increased biogas production while using the sample compared to the digester without the sample at the same temperature. However, the biogas formed at the low temperature was still low compared to the biogas produced at mesophilic temperature range (room temperature).

Context and Importance

The mesophilic bacteria responsible for methanogenesis at mesophilic temperature range are naturally found in the digestive system of ruminant livestock. However, the psychrophilic bacteria do not naturally exist in the kitchen waste or human/cattle waste. So, to generate biogas from psychrophiles, it has to be added to a digester from different sources such as bottom of lakes and swamps (Alaska Centre for Research and Power, 2009–September 2011).

The Denali Commission Research has successfully identified the potential of psychrophilic methanogens to produce biogas. The research was mainly based on the comparative biogas production potentials of mesophilic and psychrophilic methanogens at warm and cold temperatures. The feed supplied for the purpose was food waste from kitchen. Digesters containing psychrophiles produced significantly more biogas than those containing mesophiles only, at both 15°c and 25°c (Alaska Centre for Research and Power, 2009–September 2011). Another study showed that 0.66 to 0.92 m^3 m^{-2} per day of biogas (70% methane) was collected at a 10–11°c lagoon in California. (J.A Chandler, *et al.,* 1983).

The methanogenesis capability of the psychrophilic methanogens is also supported by Zhang, *et al*. (2008). The research, however, uses methanol as feed. So, the research based on the use of organic feed, which is commonly available in households, is of utmost importance to quantify the methane production and subsequently formulate parameters for digester design based on psychrophilic methanogens.

[1] CASCADE Engineering Consultancy, Anamnagar, Kathmandu
[3] Nepal Engineering College, Kathmandu

Psychrophilic methanogens have been isolated from sediment samples from the Baldegger Lake and Soppen Lake in Switzerland, using an anaerobic mineral medium supplemented with microelements and vitamins (Alla N. Nozhevnikov, 2003). A psychrophilic hydrogen utilising methanogen, Methanogenium frigidium, has also been isolated using MSH medium from the Ace Lake, Antarctica (P. D. Franzmann, 1997).

However, isolation of psychrophilic methanogens from wetlands in high altitude regions of Nepal has not been done. This research is also highly urgent to determine whether the lakes in the high altitudes of Nepal emit methane or not, as several lakes in Alaska have been shown to exhibit continuous methane bubbling (K. M Walter, 2007).

Several other technologies are being used and research carried out on them to enhance the efficiency of biogas in cold climate regions. The biogas digesters, however, use conventional mesophilic bacteria. Furthermore, these research works are mainly based on increasing the temperature of the digester by using various added systems such as solar heater, heat composting, multifunctional greenhouse and other approaches (Buysman, 2009). This approach either requires high cost or is inefficient.

Climate change has major adverse effects on forest disturbance, dispersion and shifting, biodiversity change, forest disease and pest infestations and abiotic disturbances (Gupta, 2010). Increase in temperature and decrease in precipitation can cause shifts and a decrease in vegetation (ACAP, 2012). Due to the climate change and its impact on forestry, fuelwood is scarce in rural high altitude regions, which is the major source of cooking energy in rural areas. Providing an alternative to already scarce firewood would lead to conservation of forests and address the impacts of climate change.

Furthermore, soil fertility is poor in upper hilly regions, and this problem is further amplified by the decrease in precipitation as a result of climate change. The end products of biogas digestion can be utilized as a pathogen-free, nutrient-rich fertilizer, which can significantly enhance soil fertility and also promote healthy sanitary practices (P. E. Wright) (C. T. Lukehurst, 2010).

Research Findings

All of the samples which were collected and used for testing methane production did not yield an identical amount of methane. Although biochemical test and characterization did not yield conclusive results, the reason for uneven methane production was the nature of the samples collected. Some of the sediments samples that were collected from various parts of the lakes had visible presence of organic decay, whereas some others did not have any visible indications. The digesters with samples with visible indications produced relatively high amount of methane as compared to those without any sample and at the same temperature.

The findings showed varying amounts of methane produced from the digesters with methane composition ranging from 15 to 55%. The composition of carbon dioxide in the produced gas did not show any conclusive pattern. The mass methane produced per kilogram of organic feed without any sample increased with increase in temperature. At 5° Celsius methane production was considerably low. The digesters followed the same trend with samples added in them. With increase in temperature, the mass of methane produced per kg of feed increased considerably. For comparison for mass of methane produced at 5° Celsius, the digester with the sample showed considerable increase in methane production compared to the digester without sample. This value was, however, still considerably low than the methane produced by the digesters without sample and kept at 10° and 15° Celsius. At 10° Celsius, the same pattern was followed with digester with sample producing more methane per kilogram of organic feed than the digester without sample. This value was, however, still low when compared to the methane generated by digester at higher temperature. Though the methane generated amount was high, the biogas digester would require very high amount of feed (greater than 30 kg per day) and high retention time (greater that 60 days) to be feasible for temperature of 10° Celsius. It was also seen that a digester of 4 m^3 volume was required for a family of three persons with the possibility of requirement of retention time of more than 60 days twice a year.

Methods

First, possible sampling sites were identified with the help of the available literature, which gave an idea about the possible site conditions from which psychrophilic methanogens were collected for further study. The major sites identified were the Gangapurna Lake of Manang and Gokyo Lake of Solukhumbu. Samples were also collected from swamps in the vicinities of Manang and Solukhumbu. A household survey was done in Manang VDC to determine the average amount of household waste available. Then, further steps were carried out to perform isolation of desired bacteria. Morphological and biochemical characterization was carried out for the identification of bacteria. Then, thirteen reduced scale digesters were formed with different compositions and kept at varying temperature of 5°, 10° Celsius and at room temperature.

Three of the digesters were fed with only organic waste and, in the rest of the digesters, the collected samples were added along with organic waste. Two of the digesters without samples were kept at room temperature. After 55 days of retention time, the gas composition was analysed by SAE4 multi-gas detector. The pressure developed was noted by digital pressure module (Fluke-Module PV 350) and digital multimeter Fluke DMM 117. Flame tests were also carried out. The digester was designed using standard approach, adapted by Maheta (2015). As the conventional digester design did not, however, meet the requirement, the design adopted by Maheta was changed to form new designs of cylindrical biogas digesters of volume 4 m^3 for a family of three.

Recommendations

Ongoing research on making biogas feasible at high altitude and low temperature focuses on raising temperature of digesters. The research, however, shows increased methane production with addition of samples and further increase with increase in temperature. In the present context, the use of only the sample at low temperature requires high amount of organic feed per day. Also 4 m^3 volume of digester is required to support a family of three compared to 2 m^3 volume, while operating in a mesophilic range. Hence, the initial cost turns out to be high. So, the future research should focus on formulating designs of psychrophilic digesters with the means of increasing the digester temperature or with proper insulation in the digester.

The climate change in high altitude regions of Nepal has direct impact on daily household activities. Due to shift in vegetation and reduction in soil fertility, firewood is scarce. So, it is important to implement biogas digester in high altitude regions to address the problem. Further research is, however, required to make the biogas digester feasible as an additional heating system needs to be incorporated along with addition of psychrophilic samples for increased biogas production. Based on these, the following recommendations can be made:

1. Future research should focus on addition of heating means of psychrophilic digesters.
2. Further samples should be collected from altitudes above 4,000m.
3. The subsidy for biogas digesters should be further increased for high altitude regions as the digester size of 4 m^3 is required in low temperature regions as compared to 2 m^3 for the same family size in high temperature regions.

Conclusion

The results showed that biogas generation was possible at high altitude at temperature as low as 5° Celsius. Production of methane increased when the collected samples were added with organic waste compared to when only organic waste was used. Furthermore, methane generation increased as temperature increases in digesters where samples were added as well as in the digesters where samples were not added. The samples were, however, tested in relatively macro scale by formation of prototype digesters, which were kept at varying temperatures. The analysis showed that it required 30 kg of organic feed for biogas generation in digester volume of 4 m^3, which would be enough to support family of three.

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EFFECTS OF CLIMATE CHANGE ON INSECT: PEST INCIDENCE IN MAJOR STAPLE FOOD CROPS IN DIFFERENT ECOLOGICAL REGIONS OF NEPAL

Kapil Kafle[1], Amit Khanal[1], Prakasha Acharya[1], Mahesh Jaisi[1], Roshan Subedi[1]

Executive Summary

Climate change has had an impact on insect–pest incidence globally. This study was done to assess the impact of climate change on insect–pest incidence in the major staple food crops of Nepal (viz rice, maize, wheat and potato). It also analyses people's perceptions of the trends of change of various climatic parameters and its agricultural impact across different agro-climatic zones (Terai, Mid Hills and High Hills). The study contributes to understanding the changing climatic pattern and its agricultural impact. Strengthening of meteorological studies in various agro-climates of Nepal is a must to better understand the minor effects of climate change to open the avenues for research in climate change impacts and resilience in agriculture.

Context and Importance

Nepal ranks fourth among the 170 countries rated for vulnerability to climate change. Climate change has led to changes in agriculture, primarily towards negative impact on the livelihood of vulnerable farming communities throughout the globe. The food security scenario of Nepal is of concern, with 13% of the population facing moderate to severe food insecurity (ADS, 2014). Moreover, the impact on agriculture, in particular the staple food crops, is being challenged not only by climate change but also by insect–pest incidence governed under the biotic constraints of production system, owing an average 15-20% yield losses (Neupane, 2058). Climate change has been reported to effect shift and has a positive impact on the growth and development of insect pest population; even more new insect pests species is likely to occur (Rao, *et al*., 2006; Petzoldt and Seaman, 2016 and IPCC, 2007). Similarly, climate change affects on insect population by shifting their population to higher elevation, reduce winter mortality resulting in increased pest population (Karuppaiah and Sujayanad, 2012). Nepal being endowed with various agro-climates in a very small area, the survey surveillance of insect-pest is seen inadequate and discontinuous. Therefore, this study was proposed and implemented to understand the insect-pest dynamics across the agro-climate of Nepal in the recent scenario of climate change hazards.

Research Findings

Temperature and rainfall were marked as the major climatic parameters influenced by climate change. Most of the climatic factors and their agricultural impact when subjected to respondents' view resulted in increasing temperature and an increasing uncertainty of rainfall in the country in recent years. The magnitude of change perceived, however, altered across the agro-climatic zones of the country. Increase in temperature and decrease in rainfall amount were perceived on a higher scale in the Terai as compared to the hills. The context of temperature increase as per the records of the last three decades gained from Department of Hydrology and Meterology (DHM) showed marked increase in average annual temperature in the high hills, followed by Terai and mid hills. The difference is seen as a difference in perception in a relative term of temperature across the various agro-climates. The insect pest incidence were also perceived to be increasing in recent years by the farmers. Coping strategies, mainly adoption of improved cultivar and increased use of agro-inputs have resulted in a slow but steady increase in crop productivity.

Similar results were obtained from the field research. Insect pest incidence was higher in the Terai as compared to higher elevation for all the staple food crops. In the higher elevation, new insect pests appear which were

[1] Institue of Agriculture and Animal Science, Tribhuvan University, Lamjung

not prevailing previously. This finding is supported by the literature and focus group discussions (FGDs) undertaken for this study. The incidence of insect-pest was diagnosed to be affected by climatic factors. Significant positive correlation of insect incidence with temperature was observed in rice, maize and wheat but a significant negative correlation with rainfall was observed in rice. Rainfall was seen to be negatively correlated in most of the crops except maize, but the relationship was not significant.

Methods

Fixed plot insect pest surveillance was conducted in the major staple food crops in Chitwan, Lamjung and Manang representing the three agro-climatic zones of the country. The plot layout, surveillance technique and the data collection technique were followed at a weekly interval as per methodology suggested by NICRA (2011). Further validation of the insect-pest scenario in the major staple food crops was done through Farmers' Survey and FGD. Three districts, each representing the three agro-ecological zones in each development region, were selected. Pocket areas of the major staple food crops in each district were identified as per the respective DADOs. Sixty respondents were chosen randomly in the identified sites per district, totaling 900 respondents. In addition, two FGDs per district were conducted for perception marking and validating the responses on changed climate and their impact in agriculture. Likert scale, a continuum model, was used to mark the responses and further indexing was done to conduct T-test and compare the perception of various agro-climatic zones.

Recommendations

Policy

There are no pronounced and documented policies regarding insect-pest survey surveillance with respect to climate change in Nepal. The Plant Protection Directorate under the Department of Agriculture has been performing survey surveillance in accordance with the guidelines of IPCC-ISPN 6 and has been conducting survey surveillance in fruit-fly, following the protocol they formed. Similarly, the Entomology Division of NARC, which has the mandate of entomological research does not even have a survey surveillance programme in their regular programme. Insect-pest management adaptation on the basis of crop type, crop season and changing climate is seen as necessary.

Moreover, in each climate change study, there is a requirement of large volume of spatial and temporal climatic data. In diverse agro-climatic areas such as in Nepal, there are very few meteorological study centres and databases on climatic study seem to be insufficient.

Coordination

Responsible organizations having mandate of teaching, research and extension of agriculture have failed to establish functional relationships so that they are unable to carry out synergistic efforts in this regard.

Financial provision

Climate change and its impact on insect-pest incidence are a regular phenomenon to be studied on a regular basis. There are unavailable fund regarding continuous climate change research. Moreover, the GOs and NGOs carrying out all these research must be allocated certain funds for the regularity of the project.

Sustainability

Sustainability is another concern in the field of climate change research. There has been periodic study of climate change impacts in various agro-climates of Nepal at various times, yet a comprehensive study finding is lacking, thus creating greater sustainability issues.

Future Research

- Regular insect-pest survey surveillance
- Modelling, quantifying and forecasting insect-pest incidence
- Climate change impact on major insect-pests
- Climate change resilience in agriculture

Conclusion

The changing climate is a challenge for both current and future generations. Its impacts are increasing the vulnerability of societies around the country as felt in the farmers' response. Insect-pest dynamics have been increasing throughout the country, particularly in the lower elevation. A few insect–pests (Aphids), however, have been seen shifting along the agro-climatic zone. This indicates the presence of climate change impacts on various agricultural scenes, and even in insect-pest incidence. Unlike other impact areas, the insect-pest incidence and associated staple food crop yield are subject to various other factors as well. Therefore, a continuous survey surveillance and effective relating of the phenomenon with the changing climatic pattern are to be studied. Furthermore, strengthening of meteorological study in various agro-climates of Nepal is a must to better understand the minor effects of climate change and the best adaptive measures that could cope with the climate change.

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EFFECTS OF CHANGING PRECIPITATION PATTERNS ON AGRICULTURAL PRACTICES OF FARMERS IN RAUTAHAT, NEPAL

Gopi Krishna Sedhain[1], Subodh Dhakal[2], Subhash Kumar Dhakal[1]
Ramesh Kumar Adhikary[1]

Executive Summary

The study analysed rainfall data for a thirty-one year period in Rautahat District, Nepal. The data shows no significant change in inter-annual rainfalls. There were, however, variations in the seasonal rainfall patterns of pre-monsoon, monsoon, post-monsoon and winter months in the district. VDC-wise estimation of soil moisture index indicates that it is progressively decreasing from 2000 to 2015, resulting in 80 to 100% areas under low SMI range (<0.40). As a result, farmers in this area have been changing the cropping patterns, and the productivity of major crops, except rice and maize cultivated under irrigated conditions, has decreased significantly. Gross margins for wheat and potato were already negative due to increased cost of production. Despite such negative impacts of climate change, very few farmers are using sustainable adaptation measures to minimize the effects of climate change on overall farming systems in the study areas. Use of improved seeds and chemical fertilizers, pesticides and micro-nutrients for crops production, however, has increased considerably over the past few years and yields of rice and maize were much higher in the study areas compared to district average. Wide application of hybrid seeds and high doses of chemical fertilizers, pesticides, micro-nutrients and groundwater utilization has increased the cost of production for crops in the study areas.

The majority of farmers have direct access to hybrid seeds and technologies for crop production from India through private sector. Very few farmers in the study areas have used varieties of crops such as wheat, rice and maize. It is concluded that conventional commodity-specific research in agriculture and centralized extension systems will not solve growing demand of farmers to overcome the effects of climate change in agriculture. It recommended that centralized commodity-specific agricultural research system should be modified to farming system research to facilitate generation and dissemination of demand-driven region-specific climate-smart agricultural technology to minimize the potential effects of climate change in the agriculture sector and livelihoods of people to a great extent. Besides, development and dissemination of suitable production technologies in agriculture, following research needs to be conducted for the following:

1) Farmers adaptation of recommended agricultural practices and factors affecting the rate of adoption by different communities in different agro-ecological regions;
2) Development of region-specific drought-resistant crop varieties grown under irrigated and rainfed conditions;
3) Research on cost of production of major crops grown in different growing seasons under different management regimes;
4) Research on effects of climate change on agricultural practices and associated impacts on food sufficiency and livelihoods of farmers in different agro-ecological regions; and
5) Policy research on agricultural trade and marketing, focusing on effective implementation of various safeguard measures available under various multilateral and bilateral agreements for enhancing production of potential agricultural commodities.

[1] Nepal Environment Protection Centre, Kathmandu
[2] Department of Geology, Trichandra College, Kathmandu

Context and Importance

Nepal ranks fourth in the ranking on the Climate Change Vulnerability Index, with poverty and adaptive capacity being some of the key determining factors (Maplecroft Climate Change Risk Atlas, 2011). Most climate projections for the region suggest that rainfall is likely to intensify and that extreme events will become even more frequent. Nepal's agriculture sector is highly rainfall-dependent (only 17% of irrigable land receives irrigation year round), and farmers are becoming increasingly vulnerable to the uncertainties of climate-induced weather changes (SPCR, 2010). Climate change poses a serious threat to the environment and livelihood in Nepal. Research studies, however, indicate that overall impact of changing climate is less in the Terai compared to mountain and hill regions. Analysis of cropping patterns in central Terai shows that the normal paddy cultivation time is disturbed and considerable land remains unused. The entire southern plain region of the country is most at risk from flooding. This could lead to inundation or deposition of sediments on agricultural land. Similarly, droughts—during both winter and summer—are affecting crop production and animal husbandry (NAPA, 2010).

Climate change in South Asia has significantly altered cropping seasons; increased evapo-transpiration; increased irrigation water requirements; and caused heat stress on crops and livestock. The suitable mitigation measures could be introduction of short cropping varieties; diversification of crops; introduction of heat/moisture-tolerant varieties; increased soil organic content/low tillage agriculture; water conservation crop management practices; tree planting to provide shade and fodder for livestock (Solar, 2010). Organic agriculture could be a resilience system for adaptation to climate change. Organic agriculture helps to increase resilience of farming systems through better management of soil and water, promotion of biodiversity and strengthening of community knowledge systems. Organic agriculture provides better results in many aspects of environmental issues compared to conventional agriculture (Khanal, 2009).

Agriculture also plays a significant role in making positive contributions to climate change. Improved land management practices could act as natural greenhouse gases sinks; with hotter climate, however, agriculture can either enjoy opportunities or face risks. Longer growing seasons and warmer temperatures may create opportunities for crop diversification and cultivation of new crops. Still warmer climate may mean extreme weather, pests and erosion risks. Adapting to the changing climate change is essential for the long-term sustainability of agriculture (Rai, 2012).

Potential adaptive measures to climate change include breeding of greater tolerance of crops, vegetables, livestock and fish to higher temperatures, development of low-cost water conservation technologies, development of early warning and drought and flood forecasting systems, preparedness plans for relief and rehabilitation, development and implementation of land use systems that stabilize slopes and reduce the risks of soil erosion and landslides; and construction of livestock shelters and food stores can alleviate the effects of extreme conditions affecting agriculture and livelihoods (IISD & IES, 1997).

Research Findings

Changes in rainfall patterns

The analysis of the rainfall data of the Simara Airport for the past thirty-one years (1984 to 2014) shows that inter-annual rainfalls varied widely; draughts have increased in number during monsoon and winter; and more rainfalls were received within a short duration of monsoon in the study areas. Similarly, the analysis of rainfall patterns for the past thirty-one years (1984 to 2014) in Rautahat district showed average rainfall of 1,885.47 mm. Likewise, mean maximum and minimum temperature relative humidity for twenty-eight years (1987 to 20140 was 30.45 and 18.09° Celsius and 80.79 and 66.94% respectively.

Data shows that there were no significant changes in the annual rainfall, but the number of years receiving normal rainfalls during thirty-one years shows that the average rainfall during pre-monsoon, monsoon, post-monsoon and winter seasons was below average for the 17th, 21th, 19 the and 18th years respectively. This implies that the rainfall patterns were erratic, although there was no change in total precipitation received in a year. The rainfall patterns clearly show that, every three years, average rainfall during monsoon was more than average in one year and for two consecutive years the rainfall received in all seasons in the year was below average.

This has significant impact on soil moisture index and traditional cropping patterns and yield of crops grown during summer and winter seasons.

Declining soil moisture index

The soil moisture index estimated through satellite images of study district shows that surface soils moisture content has progressively decreased from 2000 to 2015. The SMI shows that, in 2000, about 47% of the area was covered with high SMI (0.60 to 0.80); by 2014, the area with this range of high soil moisture

Table-4.1: Comparative yield of major crops grown in study areas (2016 and average for past 15 years (1999 to 2014) in Rautahat district

	Crop Yield (kg/ha)		
Major Crops	**Average Yield in Study Area**	**15 Year Average Yield of Crops in Rautahat District**	**Increased/Decreased Crop Yield (%)**
Rice	4689	2639	178.00
Wheat	1748	2276	-23.00
Maize	5837	2178	268.00
Potato	11917	15066	-21.00
Pulses	423	875	-52.00
Sugarcane	32750	36302	-10.00

index reduced to about 20% and, in 2015, the area declined rapidly and reduced to about 1%. It indicates that the surface soil of the whole district was becoming drier and drier from 2000 to 2015. The SMI estimated for all the four study VDCs also shows similar decreasing trend over the same period of 15 years, making the areas drier for cultivation of crop if irrigation is not available.

Changes in cropping patterns and farming practices

The study shows that the majority of the farmers in the study areas were aware of some of the effects of climate change and about 25% of the respondents were adopting at least one mitigation measure to reduce the potential impacts of climate change on the farming system. The study further indicates that the majority of farmers have been changing the cropping pattern, particularly in the irrigated *Khet* and *Bari* lands. In irrigated *Bari* lands, farmers have been growing vegetables during winter season, whereas in irrigated *Khet* land, farmers have shifted to maize production instead of conventional wheat and lentil crops. The study further shows that majority of farmers in the study areas have little or no knowledge of suitable mitigation measures for reducing the impacts of climate change, particularly declining soil moisture index caused primarily by erratic rainfall patterns observed in the area in the recent years. They are, however, fully aware of the decreasing yield of crops grown under rainfed and partially irrigated conditions in the areas, and many of them had switched to cultivation of drought-tolerant crops like sugarcane and even plantation of perennial crops like fruit in the uplands and rainfed areas.

Production and productivity of major crops

The study further shows that, in the study district, the average yield for rice and maize increased by about 178 and 268% respectively compared to the average for the past 15 years (1999/00 to 2013/14). The higher yield of rice and maize in the study areas is probably contributed by wider use of improved varieties, chemical fertilizers and alternative irrigation by deep boring and other better crop management practices adopted by the majority of the farmers in the study areas. It was reported that majority of the rice- and maize-growing farmers were using hybrid seeds in the irrigated field and getting much higher production compared to the open pollinated varieties used.

The study reveals that the average yield for wheat, potato, pulses and sugarcane in the study areas has decreased by 23, 21, 52 and 10% respectively. The main reasons for the decreasing yield of these crops were inadequate irrigation and declining moisture content in the soils due to erratic winter rainfalls.

Food sufficiency of farmers

The survey shows that about 59% of the households in the study area were food self-sufficient, whereas 41% were not producing sufficient food for their families. Among the 41% food-deficit households, about 62% produced food for six to eleven months and the remaining 38% for less than six months. Furthermore, about 71% of the food-deficit households purchased food with own family income, whereas 29% of the households purchased food for less than six months from own family incomes. It implies that about 18% of the households in the study area were neither able to produce sufficient food nor purchase deficit food from own income. That means they were food insecure. The study further showed that smaller landholding, natural calamities (droughts, floods, cold waves, etc), larger family size, lack of irrigation and wage rates for farm labour were the major reasons for food inadequacy.

Methods

The study employed a combination of qualitative and quantitative methods for collecting relevant data from both primary and secondary sources. Time series data on key climatic variables was collected from the Department of Hydrology and Meteorology (DHM) and production data on major crops grown in study district was collected from the Ministry of Agriculture Development (MoAD). Relevant information about socioeconomic and demographic characteristics of the sample households, cropping pattern, production and productivity of major crops, access to and application of inputs and technologies in farming with respect to adaptation measures used by community for mitigating the effects of climate change were collected through sample household survey. Qualitative information was also collected through Key Informants' Interviews, Focus Group Discussions and direct observations during field survey. The study was conducted in four Village Development Committee (VDC) areas, namely: i) Judibela, ii) Simara Bhawanipur, iii) Santpur (Dostiya), and iv) Karuniya VDCs of Rautahat district.

The data on key climatic variables like rainfall patterns for thirty-one years (1984 to 2014) and mean maximum and minimum temperatures for twenty-eight years (1987 to 2014) was collected from the DHM. Annual and seasonal rainfalls patterns for pre-moon soon, monsoon, post-monsoon and winter were analysed. Likewise, soil moisture index for fifteen years (2000, 2014 and 2015) was estimated using freely available satellite images. Time series data on productivity of crops grown in the study district for the past fifteen years (1999/00 to 2013/14) was collected and regression analysis was conducted to observe the relationships between the crop yield and seasonal rainfall pattern. Similarly, gross margin and cost–benefit ratio of major crops grown in the study district was analysed using the cost of production data obtained from the Agribusiness Promotion and Statistics Directorate and sales prices data collected from the household survey.

Recommendations

- **Development and dissemination of suitable crop varieties:** Review of the list of released crop varieties by Nepal Agricultural Research Council (NARC) shows that a few alternative varieties of rice, wheat and maize have been released to cope with potential droughts in different agro-ecological regions of Nepal. Majority of farmers in the study areas were, however, not using these crop varieties due to low productivity compared to hybrid varieties easily accessible to the farmers in the Terai region. Therefore, on-farm trials of recommended crop varieties, along with package and practices of production under both irrigated and rainfed conditions, should be carried out so that farmers can observe and analyse the comparative benefits of recommended crop varieties and practices, as well as conventional and hybrid seeds used in the study district.
- **Change in cropping pattern:** In the study district, the farmers have been planting the same crops irrespective of changes in the rainfall pattern. When monsoon is delayed and planting conventional rice crops is not possible, the farmers should be encouraged to go for other alternative short duration crops like millets, legumes and other cash crops such as vegetables.
- **Diversification of crops:** Research in integrated farming system is limited in Nepal and monoculture of a few crops is being promoted for commercializing agriculture. This has increased both the cost of production of crops and risks of crop failure, especially for small and marginal farmers without access to irrigation. Therefore, integrated seasonal crops, horticulture and livestock production system should be developed and promoted to increase the total farm incomes by minimizing the risks of crop failure.
- **Promotion of application of organic manure:** Analysis of soil moisture index (SMI) in the study areas shows that, in the northern part of Judibela VDC, the index was much higher in the areas with under moderate to high soil moisture compared to the other three VDCs in the southern region where the dominant ethnic groups are the hill populations who kept at least a few cattle, buffaloes and goats and applied farmyard manure in the field. Therefore, the farmers should be encouraged to revive crop–livestock integrated farming system so that the majority of small farmers can produce adequate farmyard manure for crops. Research findings suggest that application of reasonable amount of organic manure not only adds organic matter to the soil but also improves the water-holding capacity of the soil and increases efficiency of fertilizers, enhancing the drought-tolerant capacity of the crops grown. The organic matter also extends the soil moisture for longer periods, saving the crop from water shortage in the post-monsoon period.
- **Promotion of micro-irrigation technology:** There is significant yield gap in the crops grown in rainfed areas when a drought occurs. Therefore,

suitable micro irrigation technology and other soil moisture conservation practices should be promoted among the farmers, particularly in rainfed areas, which would have significant impact on increasing the crop yield.

- **Groundwater development:** A considerable number of farmers in the study areas were using groundwater for irrigating crops, and the government is also providing subsidy for installation of shallow and deep tube-wells for farmers. There are, however, no programmes for encouraging farmers for developing suitable infrastructures for groundwater re-charging through farmers' participation. Dug wells and recharge wells should be constructed in the northern side of the district, which could very easily be converted into a form of groundwater recharge structure where water received during monsoon or floods can be recharged into the ground. It would upgrade the water table, which can be sustainably pumped and used for production of high value cash crops during the non-rainy season.
- **Weather Forecasting System:** Review of available literature on climate change and adaptation measures in Nepal indicates that no weather forecasting system has been developed yet. Therefore, the national agency concerned should develop reliable weather forecasting systems to allow farmers and agencies that deal with droughts, floods, cold waves and hailstorms make contingency plans to cope with likely potential emergency situations in different ecological regions of the country.
- **Seasonal rainfall forecast for different ecological regions** of Nepal is currently not available. Therefore, seasonal rainfall forecasting system should be developed for each major geographical region of the country so that researchers and planners engaged in development and dissemination of agricultural technologies for farmers can develop suitable mitigation measures for reduction of potential effects of climate change on the agriculture sector.

Future Research

- Farmers' adaptations of recommended agricultural practices and factors affecting the rate of adoption by different communities in different agro-ecological regions;
- Development of region-specific drought-resistant crop varieties grown under irrigated and rainfed conditions;
- Research on cost of production of the major crops grown in different growing seasons under different management regimes;
- Research on effects of climate change on agricultural practices and associated impacts on food sufficiency and livelihoods of farmers in different agro-ecological regions; and
- Policy research on agricultural trade and marketing focusing on effective implementation of suitable safeguard measures available under various multilateral and bilateral agreements to encourage farmers for increasing production of potential agricultural commodities.

Conclusion

Analysis of annual rainfall patterns, monthly mean maximum and minimum temperatures, and relative humidity shows no significant changes over the past thirty years in the study district. Soil moisture index in the district has, however, decreased significantly over the past fifteen years, leaving most of the arable lands drier for crop production if irrigation water is not available.

Despite large-scale application of improved crop varieties and other inputs, the average yield for most crops except rice and maize has not been decreasing and the gross margin of major crops has also been decreasing and even negative for wheat and potato. The traditional crop-livestock integrated farming system has already disintegrated with forced mechanization and subsidized chemical fertilizers. Most farmers are cultivating only one or two crops a season, and diversity in crop production has been decreasing rapidly and there is potential risk of crop failure due to infestation of diseases, impotency of hybrid seeds to bear seeds and high competition in domestic markets for crops grown in large areas by many farmers in the same season. As a result, food security of small and marginal farmers may be threatened due to increased dependency on purchased foods. Despite use of improved seeds and high cost inputs, the productivity of crops such as wheat, potato, pulses, sugarcane and fresh vegetables has been decreasing in the study areas over the years and the net profit from wheat and potato production in the area has already been negative for farmers.

The study indicates that high gross margins from hybrid seeds and costly inputs motivated farmers to change the cropping patterns with fewer crops in irrigated conditions. Increased application of high dose of chemical fertilizer, insecticides/pesticides, groundwater resources and even changing the land use pattern have increased risks to farmers. In the study areas, the areas under rice and wheat cultivation have been decreasing and the areas under cultivation of sugarcane and other cash crops are increasing.

The study indicated that the majority of farmers have not been using sustainable adaptation measures like changing time of farm operations, changing farming systems, including use of drought-tolerant crop varieties, manipulation in planting and harvesting timing for crops, diversification of crops and integration of crop production with livestock and agro-forestry system which are considered sustainable measures to reduction in adverse impacts from climate change.

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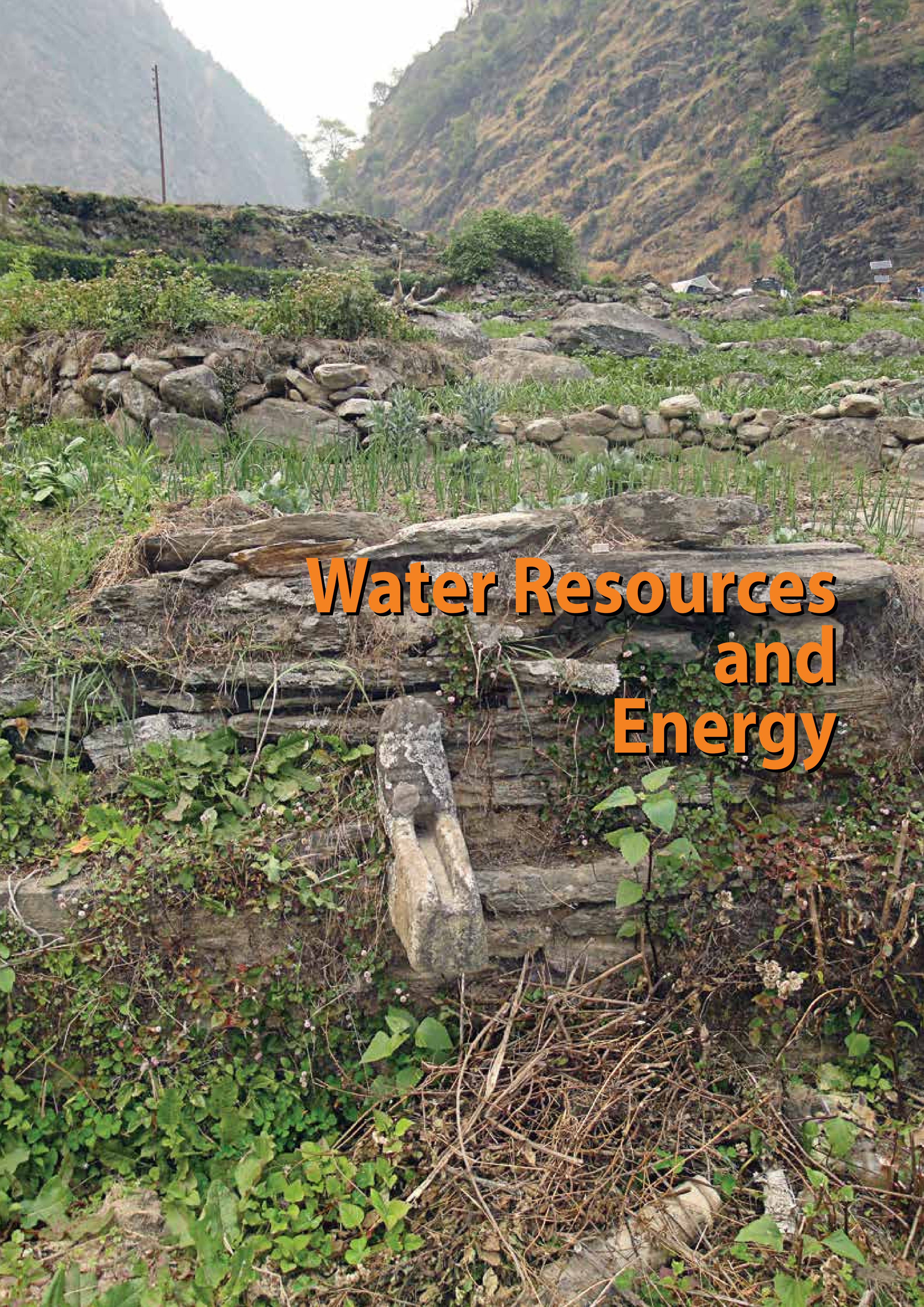
Water Resources and Energy



ESTIMATION OF SNOW-MELT RUN-OFF FOR HYDROPOWER PROJECTS IN DIFFERENT CLIMATE SCENARIOS IN NEPAL

Narendra Man Shakya[1] Rajendra Bahadur Chhetri[1], Manish Bhandari[1]

Executive Summary

Himalayan glaciers have been retreating in the accelerating pace of global warming. The impact of global warming on the glaciers and ice reserves of Nepal will have serious implications for fresh water reserves and, consequently, for low flows. The implication is the declining of ice reserves affecting the dry season discharge in the future. A conceptual precipitation runoff model is, thus, used to simulate the daily runoff from glacierized sub-watersheds of basins of Nepal, which is the major tributary of the Ganges River (India). Snow and glacier melt are calculated by surface energy balance and mass balance modes (EBM). For the determination of snow and glacier areas to be used in EBM, LANDSAT TM7 image was processed by using ERDAS IMAGINE. The glacier melt under the debris layer is estimated from thermal resistance to critical thermal resistance ratio. The ratio has been estimated from surface temperature of the debris obtained from spatial modelling of the Landsat. The estimated runoff from the melts is then routed downstream to basin outlet in plain via major tributaries using semi-distributed rainfall-runoff model. The likely impact on the same in future due to climate change is also analysed using AR5 scenario. The analysis indicated that snow and glacier melt alone contributes to the Gandaki Basin about 7.40% of the total annual flow at Narayanghat. The contribution is more significant in dry periods, in which snow and glaciers contribute about 13.68%. Similarly, in the Karnali Basin snow and glaciers contribute about 10.13% of the total annual flow and about 13.69% of the dry period flow, and 7.87% of the total annual flow of the Koshi River at Chatara is contributed by snow and glacier melt. This figure increases to 12.02% during dry periods.

Analysis carried out using projected climate scenario suggests that, in most of the sub-basins the annual flow volume, as well as 40% reliable flow, will decrease in 2030 but increase in 2050. The result thus indicates that the available flow for Run-of-the-river (RoR) and storage hydropower projects will decrease in 2030 A.D. But the flow will increase in all the sub-basins in 2050 A.D. if the area of snow and glacier cover remains unaltered. The study demonstrated that the impact of climate change (ie temperature) to stream flow is significant, which is in increasing trend, resulting from snowmelt contribution. For further study and refinement of the research, it is commendable to establish meteorological stations within the catchment itself, use the more precise and more number of satellite images (at least one per each month in depletion period). The output of this study is an important guide for water resources managers to make and implement appropriate strategies for water resources planning and management.

Context and Importance

Himalayan water budgets and the state and fate of Himalayan glaciers have attracted considerable debate in both the scientific community and mainstream media. Himalayan glaciers are clearly thinning and retreating, but the signals of change are spatially complex. In addition, the behaviour of summer monsoonal rainfall has been erratic during the past few decades, making it more difficult to predict available water resources. As a result, transient storage in the form of snow and ice has become a focus of attention (Scherler, *et al.*, 2011). Fluctuations in river discharge can impact the production of already built projects and potential generation from the "to be" built projects. Hence, climate change and its impact on river hydrology has been a major concern for hydropower development (Sharma, et al., 2013). The melt-water contribution of glaciers is particularly important for hydropower

[1] Tribhuvan University, Institute of Engineering Pulchowk

projects during dry seasons and temperature trends are important for the fate of glaciers.

Most of the hydropower projects of Nepal have been planned in the Himalayan River Basins with the aim of utilizing the pre-monsoon snowmelt to generate energy during the dry season. The installed capacity of such hydropower projects is highly sensitive to dry season flow of the river. The installed capacity of the projects is fixed based on empirical methods. Such empirical methods are derived from very limited observed information. Thus, the reliability of the prediction of the dry season flow of the river is very low. As a result, during dry season, most of the run-off river type hydropower plants generate much less energy than they are supposed to as per planning. Therefore, it is necessary that the contribution of snow-melt to the river discharge and its future variations eventuated by climate change be studied rigorously and accounted for during the planning of hydropower projects in order to ensure utilization of related structures and installations, especially during the dry season when there is acute shortage of natural stream flow.

Most hydropower plants in Nepal are, however, run-of-the-river (RoR) installations and are, thus, severely affected by the existing seasonal variations in the river flow. Nepal's current hydropower system is ill-prepared to even address the current variability of flow, let alone any hydrological changes due to climate change. The current electricity tariff offered by the electricity utilities to private developers are about two times higher in the four dry season months of mid-December to mid-April than in the other eight months of the year. These mean that any changes in the total annual flows, which are mostly monsoon flows (about 75-80% of annual flows are in the four monsoon months), is less important than the changes in the dry season months. This highlights major adaptation deficit at present and immediate adaptation options to address the current deficit through a mixture of supply and demand measures is warranted.

The main goal of this research project is, therefore, to develop a comprehensive understanding of the dynamics of snow and glacier melt water to the river discharge during the dry pre-monsoon summer when the amount of water available in the stream falls to the minimum. This research aims to use the first principle approach to account for the dynamics of snow and glaciers using remotely sensed information for simulating the contribution of the snow and glacier melt runoff to the stream flow discharge.

Research Findings

Snow melt and ice ablation from the debris covered glacier area has a remarkable influence over the river discharge of Nepal. The analysis indicated that snow and glacier melt alone contribute about 7.40% of the total annual flow to the Gandaki Basin at Narayanghat. The contribution is more significant in dry periods, in which snow and glacier contribute about 13.68%. Similarly, snow and glacier contribute about 10.13% of the total annual flow and about 13.69% of the dry period flow of the Karnali River at Chisapani. Of the total annual flow of the Koshi River at Chatara, 7.87% and during dry period, 12.02% are contributed by snow and glacier melt alone. For smaller basins like the Dudhkoshi River the contribution of snow and glacier melt is 21% at Rabuwa Bazaar during dry season.

The study demonstrated that the impact of climate change (ie temperature) to stream flow is significant, which is in increasing trend, resulting from snowmelt contribution. Analysis carried out using future climate scenario suggests that, in most of the sub-basins of Nepal, the annual flow volume, as well as 40% of the reliable flow, will decrease in 2030 but increase in 2050. The result, thus, indicates that the available flow for RoR and storage hydropower projects will decrease in 2030, but the flow will increase in all the sub-basins in 2050 if the area of snow and glacier cover remains unaltered. The study demonstrates that the impact of climate change, ie temperature, to stream flow is significant, which is in increasing trend, resulting from snowmelt contribution.

In most of the basins, there will be shifting of hydrograph, indicating delay in monsoon. Also, there will be irregular peak of flow caused by short burst of high intensity rainfall.

For further study and refinement of research, it will be worthwhile to establish a meteorological station within the catchment itself, use the more precise and more number of satellite images (at least one each month in the depletion period). The output of this study is an important guideline for water resources managers to formulate and implement an appropriate strategy for water resources planning and management.

Methods

Simulation of watershed having snow and glacier areas requires approaches different than conventional hydrologic simulation of non-glacier areas. In this study, the component of glacier and snowmelt was also considered during hydrologic simulation of the whole watershed. So, this has divided the whole study into two major sections: snow and glacier melt runoff simulation and rainfall runoff simulation. For analysis of the first section, necessary satellite images and DEM were downloaded from the respective sites. Analysis of these downloaded images in ERDAS IMAGINE and ArcGIS gives the area of snow and glacier (both debris covered and clean ice). The glacier and snow area data, thus, obtained is used as an input along with meteorological data to determine the snow and glacier melt volume, which is again given as input to the conceptual TANK model to generate the hydrograph of the stream at the basin outlet. Next, rainfall runoff simulation is carried out by using the HECHMS semi-distributed hydrological model. After the simulation of the model, contribution of snow and glacier melt at the basin outlet is determined, both annually and in the dry season. For determining the effects of climate change, precipitation and temperature data obtained from AR5 scenario is used. Finally, the effects of climate change on stream flow are analysed.

Recommendations

Understanding how a water resources system responds to changing trends and variability requires knowledge of how it is affected by those conditions today and how it might respond in the future if those conditions change. Assessment of climate change helps to build resilience to the possible impacts of climate change through enhanced institutional flexibility and consideration of climate-related risks in the planning process. The impact of climate change on water resources depends not only on changes in the volume, timing and quality of stream flow and recharge but also on system characteristics, changing pressures on the system, how the management of the system evolves, and what adaptations to climate change are implemented. Non-climate changes may have greater impact on water resources than climate change in managed basins, but the unmanaged systems are likely to be most vulnerable to climate change. Climate change challenges the existing water resources management practices by adding to uncertainty.

Climate change and climate risks in general are neglected in the country's development policy. In order to integrate and mainstream the impacts of climate change into the various activities of the water sector agencies, reform in policy, design and construction of system is indispensable. This study provides science-based information on how future climate change will affect glaciological and hydrological systems in the Nepal Himalayas in order to mainstream climate change risk management in water resources development. The results also substantiate the need for a policy for early planning for the future impacts of climate change, noting uncertainty. This includes focus on the value of information and future options and learning. Furthermore, this includes actions that will help inform the future hydro-electricity sector, ie to help improve future decisions, particularly around enhanced monitoring and research.

Mainstreaming is accomplished by incorporating climate risks and weather extremes into short-term decision-making as well as long-term visions. In addition, current engineering practices should be modified since they often take into account historical climate, which may not be suitable for predicted future climate and extremes. On the other hand, mainstreaming climate change into engineering projects is only possible when adequate levels of capacity and development exist.

High priority should, thus, be given to the monitoring of the present status of the country's water resources, current runoff trends, minimum flows and similar metrics. Actual precipitation (and runoff) data are required for more enhanced and more accurate future analyses of rainfall–runoff relationships and hydrological modelling. Therefore, the existing hydro-meteorological networks in Nepal should be revived, upgraded and expanded, with particular emphasis on the collection of runoff data. Equal priority should be given to the preparation of a comprehensive and nation-wide database of already available hydro-meteorological data. Thus, in support of the development of the hydro and other sectors such as agriculture, there is an urgent need to develop and operationalize a comprehensive Hydrological or Water Information System (HIS/WIS) for Nepal.

In 2010, the government published the National Adaptation Programme of Action (NAPA) to Climate Change, which is a strategic tool to assess climate vulnerability and systematically respond to climate change threats by developing appropriate adaptation measures. There are, however, still large gaps in the legal framework and institutional capacity to implement the proposed framework. Those policies, therefore, need to be backed with legislation and resources to ensure effective and efficient implementation of the Climate Change Adaptation (CCA) measures. Another option could be to extend the existing EIA legislation to include the CCA criteria.

Future Research

In this study, satellite images of 2001 and 2013 are used to determine the change in snow and glacier cover. This change is not enough to represent future changes in snow and glacier cover since the change in snow and glacier cover is not linear. There are a number of factors such as temperature, wind speed, radiation, precipitation, relative humidity and albedo, which affect the snow and glacier melt. Due to this reason, in this study, the glacier and snow cover area is taken as constant for years 2030 and 2050 during the analysis of climate change. For future studies, the changes in snow and glacier area should be incorporated for analysing the climate change impact. For this, a suitable model can be developed to incorporate the different factors affecting glacier retreat for the estimate of future area of snow and glacier.

As a consequence of changes in precipitation and temperature, hydropower plants are threatened by precipitation-induced natural disasters, notably floods, landslides, and severe erosion and sedimentation problems associated with the summer monsoon. Moreover, there is an increasing risk of Glacial Lake Outburst Floods (GLOFs) due to accelerated glacier melt caused by increasing temperature and the subsequent retreat of glaciers. It is these threats that hydropower developers fear may increase in the future due to increasing variability of precipitation and increasing temperature. A stronger focus on research and monitoring of these variables and early planning to see how to respond to them is, therefore, a priority to start preparing for future climate change.

Conclusion

Snow and glaciers of Nepal have substantial contributions to sustaining flow in lean period. The impact of climate warming on the glaciers and ice reserves of Nepal will have serious implications for the freshwater reserve and, consequently, for low flows. On the other hand, there is a danger of declining of ice reserves due to climate warming. This will adversely affect the dry season flow in the future and will have serious adverse impacts on electricity generation from hydropower plants, especially for run-of-the-river type plants, water supply and irrigation planning and also on biodiversity. When there is change in seasonal flows, electricity generation might be affected significantly, even without the change in annual flow volume. In order to compensate the likely reduction in contribution of melt flow from snow and glacier to the river system during the lean flow season, appropriate basin scale interventions to enhance base flow of river system are imperative. Such conservation measures can only be possible once there are dedicated and precise policies and legislation related to Integrated Water Resources Management and River Basin Management. Similarly, appropriate policy for the implementation of generation mix storage project, ie use of run-of-the-river (RoR), peaking run-of-the-river (PRoR), in conjunction with thermal plants is required in this regard.

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SITUATION OF SPRINGS, GROUNDWATER SPRING POTENTIALITY AND GENDER ROLES IN WATER MANAGEMENT: A STUDY OF MELAMCHI AREA, SINDHUPALCHOK, NEPAL

Prem Sagar Chapagain[1], Moti Lal Ghimire[1], Shova Shrestha[1]

Executive Summary

Nepal is one of the highly vulnerable countries in terms of climate change effects. Water is one of the natural resources essential to life and the environment. The majority of the mid-hill people of Nepal depend upon springs for this resource. The mid-hill springs are severely affected by climate change as they are drying out and flow has reduced. But there is no information and knowledge base on the various aspects of springs, especially in the context of climate change. The Melamchi watershed area of Sindhupalchok, from where the water of Melamchi is planned to be brought to Kathmandu for drinking purpose, is one of such areas and hence selected for the study. More than 90% of the springs are permanent. Out of the total springs (412), 73% are at 1,500-2,500m elevation. The springs are located in forests (47%), bush (24%) and agriculture land (13%). The springs have varying discharge rate and one-fourth have less than 5 litre/minute discharge. Of the water of all springs, 74% is utilized, and majority (46%) of the springs serve less than five households. Water volume of about 30% springs has decreased over the last ten years. Significantly, 18% of the springs have dried/disappeared due to the 2015 earthquake, which directly affects 22% of households in the Helambu, Kiwool and Baruwa VDCs. The springs located at 1,500-2,500m elevation with lower discharge (<5 l/m) are found to be more vulnerable. Local people also claim that temperatures will increase and precipitation will be less and erratic. This will affect local springs so that water scarcity will increase in the future.

Weight of multiple classified factors indicating the probability of groundwater spring occurrence reveals the deterministic distribution of groundwater springs in the study area. Maps indicating potential areas of spring occurrence have a high predictive and success rate. Of the total area studied, about 16.7% lies in zone of high spring potential, 23.2% in moderate, 37.4% in low and and 22.8% in very low potential spring zones. About 92% of the house units in the study area are located in high groundwater spring potential zones. Soil moisture estimation is based on the triangular relationship between soil moisture, land surface temperature and vegetation density. Correlation and regression analyses were carried out to relate the Temperature Vegetation Dryness Index (TVDI) against in-situ soil moisture measurement data during the dry season. A significantly negative relationship exists between the TVDI and in-situ measurements. Spatial and temporal patterns within the dry season were also observed. The TVDI index can be feasible for monitoring the surface soil moisture dynamics during the crop-growing seasons and can examine the critical water requirement for the crops.

Decreasing water volume, compounded with geographical proximity of water availability over rugged topography, determines the accessibility and hence has increased women's workload in terms of distance covered, time spent and frequency of everyday water collection. Scarcity of drinking water was the obvious perceived future risk at community level, whereas search for new water sources is a potential future risk perceived by women. Different capacity and vulnerability of men and women was also evident. Although realized, climate change effect was perceived as less important due to its gradual effect over other immediate problems where the cost of water collection is borne by women.

Context and Importance

Water is the fundamental natural resources to life and environment. Springs are the major sources

[1] Central Department of Geography, Tribhuvan University

of water and they have a major role to play in the livelihood and environment of the Mid Hill ecosystem of Nepal, but they are drying out and their flow has reduced during dry seasons (Practical Action, 2007; Regmi, *et al*., 2008; ICIMOD, 2009; ANU, 2013). There is, however, a lack of information and knowledge (WECS, 2011) in relation to springs. Water availability and quality are the main pressures and will also be the issues for society and the environment (IPCC, 2007). Many studies from the Koshi Basin reported drying out of springs and declining amount of water in the existing ones in the last three decades (ICIMOD, 2009; 2015; Dixit, *et al*., 2009; Peking University and TU, 2013). The draft National Water Resource Policy (2011) of Nepal has also recommended identifying and mapping available sources of water. The formulated action plan focused on identifying, survey and mapping, and keeping records of surface and groundwater sources. Importantly, water from Melamchi is being supplied to the Kathmandu Valley through pipeline for drinking. Thus, studying the changing characteristics of springs, water potentiality, and water supply situation at local level is of prime importance in the context of climate change and the recent earthquake.

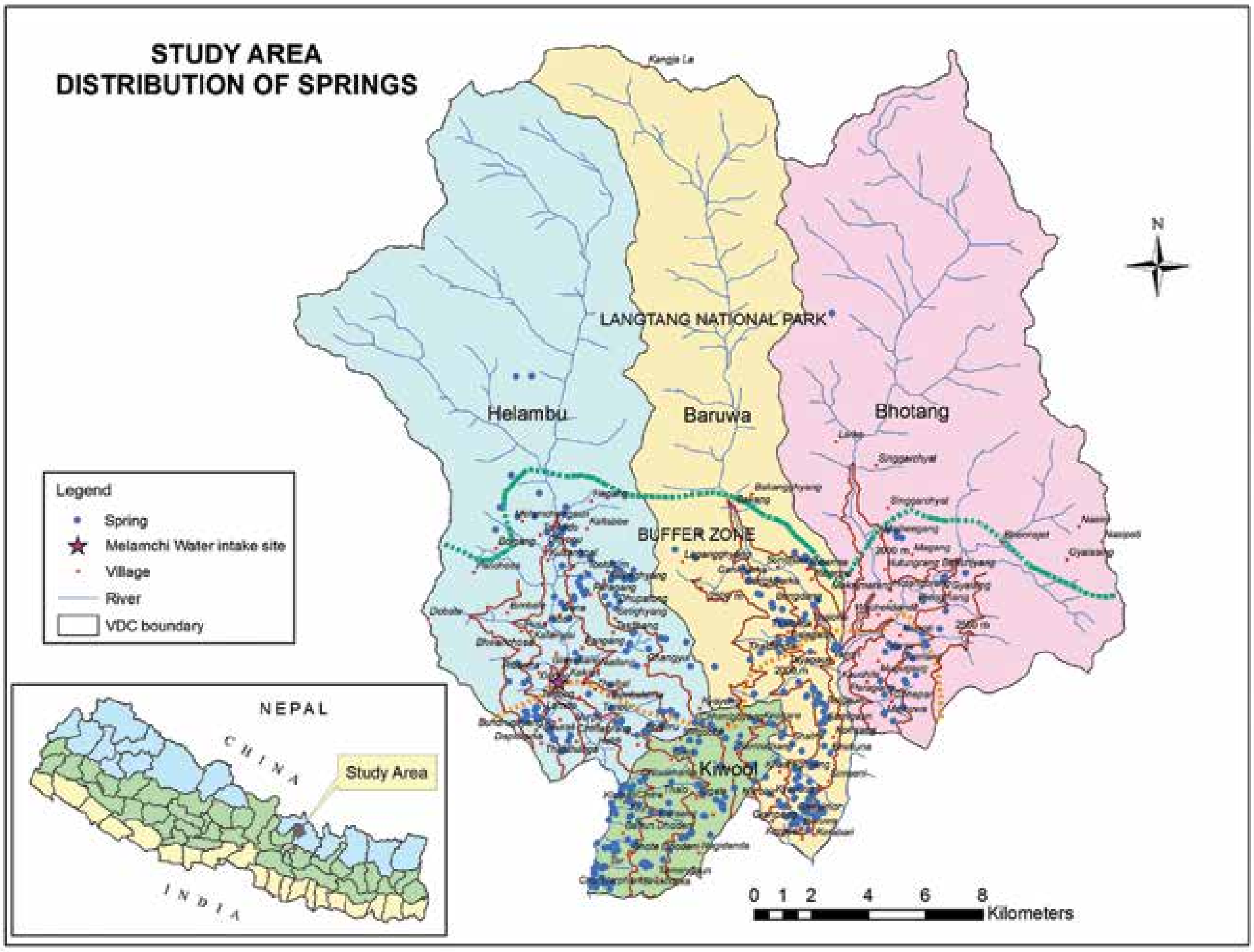
Research on mapping groundwater spring potential and soil moisture availability has recently become urgent in Nepal in the context of climate change and variability, land use and socioeconomic changes. Understanding the relation of springs with factors controlling their occurrence can be important for locating potential zones of groundwater springs. Similarly, the earth surface environmental parameters such as surface temperature and vegetation measured by remote sensors can fruitfully be applied for monitoring soil moisture or dryness index. The climate change and variability have further induced the risk of drought in agriculture, which heavily depends on rainfall (>64%) and naturally available moisture. The method and findings of research on the groundwater spring and moisture estimate can be instrumental for policymaking and planning of water resources management.

Gender elements in climate change include different ways that men and women respond to and are able to cope with climate change and the differences in how they are able to move from short-term coping mechanisms to adaptation and resilience (Ongoro and Ogara, 2012). From gender dimensions of water access and management, the primary responsibility of collecting water for household and livestock is assigned to women, while men use water for irrigation and industries (Fisher, 2006). These distinct roles mean that women and men often have different needs and priorities in terms of water use. Studies exemplify that changing climate can increase the already high labour burden for women. Considering the time spent by women to collect water at present, increased water scarcity in the future may mean women and girls have to spend more time on this already arduous task (Sugden, *et al*., 2014). Though the issue of gender and power inequalities is an important one, a research gap still exists as compared to contextualizing the vulnerability regarding gender and climate change. Geographical marginalization and vulnerability are often largely ignored, which is the core of inequalities in power (Arora-Jonsson, 2011). Furthermore, the decrease in water resources by 50% in the mid hills of Nepal must have implications for time, cost and access to women. (Gurung and Bisht, 2014). Study of existing water access and management and local perceptions and experiences from gender perspective is thus imperative in addressing and minimizing the risk of climate change at local level.

Research Findings

The study identified 412 springs. Out of all springs, 93% are permanent. In terms of land use, 47% springs are in forestland, followed by 24% in bush/grass land and about 13% are in agricultural land. In terms of elevation, 73% are at 1,500-2,500m and density decreases with increasing altitude. In terms of slope, there are more springs in the west and south aspects compared to the east and north aspects. The discharge rate of springs is quite varied. The discharge rate of about 25% springs is below 5 litres per minute. Out of all springs, 74% are used for various purposes at household level. In terms of households served, 140 (46%) springs served less than five households each, whereas 66 springs (22%) served from five to ten households each. Furthermore, the water of about 74% (305) of the springs is utilized for various purposes. Multiple uses are common, with 86% of the springs used for various purposes.

Over the last thirty years (1979–2009), temperature of in the Melamchi Valley rose by 1.02° Celsius. Drought period has increased from two months in 2005 to nine months in 2012. The water volume of 30% springs has decreased over the last ten years. Importantly, 18% of the springs had dried/disappeared due to the 2015 earthquake. About 70% of the dried springs were at 1,500–2,500m elevation and used to serve water to 22% of the households of the study area.



It shows that the water of majority of the springs decreased by 25-50%. Local people were aware of the changing water situation and expected that the water crisis will further increase in the future primarily due to climate change and also because more springs will dry up in the future due to the Melamchi water tunnel.

A groundwater spring potential zone map was prepared using weight of evidence. The predictive and success rates of 81 and 80% indicate the validity of the method adapted. Groundwater spring potential tend to be high on lower altitude gentle slopes, low relative relief, north and east facing slopes, high flow accumulation area, high drainage density and in densely vegetated area. Of the total area studied, about 16.7% lies in zone of high spring potential, 23.2% in moderate, 37.4% in low and 22.8% in very low potential spring zones. About 92% of the house units are located in high groundwater spring potential zones. Similarly, satellite imagery-based Temperature–Vegetation Dryness Index maps, indicating relative soil moisture condition of time points of dry months (December–March) for 2001–2016, were calculated. TVDI map of February 2016 significantly correlated with in situ soil moisture measurement data. All TVDI maps showed a consistent relationship between them, which indicates a general situation of moisture distribution during dry months. Higher moisture index was found for the cultivated patches located at convergent and concave parts of lower slopes as compared to higher and divergent slopes.

The findings show that there is an immense difference between men and women in the time devoted to activities. Overall, men work 15 to 16 hours and rest for 9 hours, whereas women work 18 hours and rest only for 6 hours. Variable labour hours are obvious in activities like rest/sleep, cooking, water fetching and community and social involvement. Apparently, no time is spent on community and social involvement by women while no time is spent by men on cooking. Overall, 85% of the water collection activity is carried out by women. There exists gender bias as women travel farther than men to collect water. More than 56% of women travel beyond 1 km and up to 4.5 km. More than 46% of women spend a minimum one to three hours to fetch water, whereas a majority of men fetch piped water and spend less than 15 minutes. No distinct management practice is visible;

no dominant geographical and cultural disparities are found in household water management practices. Restrictive use and increasing frequency of water fetching is, however, a common adjustment adopted by women during dry season, hence, the result is increased workload. A lower percentage of drinking water use in Kiwool VDC and relatively high percentage in other three VDCs demonstrate cultural diversity between hill ethnic groups and Brahmin/Chhetri groups in drinking water use.

Methods

The study adopted an integrated approach involving both biophysical and socioeconomic aspects. The spatial digital database was prepared based on the available recent maps and remote sensing images. Climate data (rainfall, temperature), demographic and socioeconomic and other related information were collected and integrated with the spatial data. A onetime detailed Global Positioning system (GPS) survey of spring location was carried out in the dry season. Furthermore, detailed information on each spring with respect to its locational characteristics, permanency, discharge, ownership, changing volume, number of households served, management situation within last 10 years, and the recent earthquake impact were collected from key informants and water users of the respective springs and nearby local people. A detailed household survey was conducted based on randomly selecting the 10% households (269) of the study area. Daily activity profile and capacity and vulnerability matrix were devised for the gender analysis. Two FGDs (12–15 participants per FGD) were conducted in each of the four VDCs (total 8 FGDs) to collect and verify information on the characteristics of springs, perceived and experienced effects and gender roles. These data were further integrated into the GIS system and further analysis done.

Considering the effective role of terrain factors or their proxy representation of physical parameters to determine the groundwater potential, 10 data layers of the factors altitude, slope gradient, slope shape, relative relief, flow accumulation, drainage density, geology, land use, and vegetation density were extracted from the spatial database. GIS-based weight of evidence method by overlaying distribution of surveyed groundwater spring locations with multiple class factor layers was applied to identify groundwater potential zones. The result was validated by predictive and success rate analyses with all springs, as well those springs that were not included (10%) in the analysis. For estimating soil moisture TVDI of post-monsoon dry months (December–February) was calculated from the Landsat imageries of 2001–2016. TVDI analysis was done on the basis of triangular relation between soil moisture, land surface temperature, and NDVI of the study area calculated from imageries of thermal, red and Infrared bands. Regression analysis was done to examine and verify the relation between TVDI and the in-situ measurement of moistures of 42 soil samples collected at different locations.

Recommendations

Climate change has highly affected various environmental resources, ie water, forest, pasture productivity, in the Himalayas, though there are still uncertainties regarding the level of its effects. The importance of environmental resources in the context of Nepal and the study area in particular is undisputed in that local people have been dependent on these resources for their livelihood for a long time. Water is a key to life. Springs are not only the major sources of water for drinking, irrigation, washing/cleaning, livestock feeding, but also sources of stream where on which local grinding mills (*ghatta*), micro-hydro, hydro power, recreational activities, and aquaculture are dependent.

- Systematic efforts of the government at local and national level are very urgent to save/conserve springs. Springs play an important role from social, cultural, economic and environmental aspects in the Mid hills because springs are the major sources of water. A total of 43% of the country's population is dependent on springs. It has become highly urgent to address this through policy and to establish a unit/section under the appropriate ministry of the Government for addressing the problems.
- There is no systematic studies and database of springs in Nepal. Such database is to be prepared at local level by VDC and by watershed so that effective planning, monitoring and management of water for various purposes can be made. Finally, a time series data of springs needs to be prepared at the national level so that the effect of climate change and other global change processes can be monitored.
- The importance and management of springs and conservation-related studies are to be included from junior level to the higher level of studies and research. The research on changing situation

of springs and the conservation and adaptation mechanisms for them that local people have imitated or developed must be documented and the best practises suitable to the particular local are to be replicated, especially in the mid hill region.

- A comprehensive water scarcity adaptation plan is to be developed at local level. It should be an integral part of LAPA and NAPA, and other climate change policies.
- Conservation and management of springs of the study area is of prime importance for the sustainable water supply of the Melamchi River to Kathmandu. Thus, the authorities concerned should immediately start spring water recharge activities and other management activities in the Melamchi, Larke and Yangri watersheds. It should prepare a sustainable spring water conservation master plan of the Melamchi area.
- Mapping of groundwater potential zones based on the application of geo-information technology integrated with a field survey should be promoted for development of water resources database for water resources management.
- The application of space science technology in assessing soil moisture or drought index should be promoted as it has been demonstrated to be a cost effective and reliable method.
- Presence of water sources in a particular location does not confirm easy access. Geographic proximity and water availability determine the travel distance and time spent on water collection. A community-level mechanism should be developed to encourage participation of women in water access utilizing their environmental acquaintance and local knowledge.
- Local people are adapting to different alternatives during dry season as conventional practice and they are aware of potential climate change effects. Climate change effect is, however, perceived less important due to gradual effect over other immediate day-to-day problems largely because the cost of water collection is borne by women. Sensitization should be focused at all levels and among all stakeholders beside awareness of climate change risk management programmes.
- Study of climate change effects in geographically marginalized area requires a detailed understanding of cultural diversity, men's and women's local knowledge, resource utilization and management practices. Gender disaggregated data and information generation and context analysis at lowest administrative scale should be introduced so that information base complement comparative and trend analysis for future research within the LAPA framework.

Conclusion

Springs are the lifeline in the Mid Hill region. They are, however, drying out and water volumes have been decreasing due to climate change and other processes. Two-thirds of the springs are at mid elevation (1,500–2,500m) and their density goes on decreasing with increasing altitude. Springs with low discharge rate located at mid elevation are rapidly drying out. There is no systematic effort in research and management of springs. The spring's database at local to national level should be prepared by establishing an appropriate department under the government. Water scarcity/management plan should be developed at local level. Furthermore, there is greater need for awareness generation through placing it in the curriculum of formal studies at schools, workshops and other appropriate means at different levels.

High spring potential areas are represented by low altitude, gentle and concave slopes, low relative relief, concave slopes, high upslope contribution area, and high vegetation density area. GIS and RS groundwater spring potential maps calculated from WoE method for each multi-class factor can be reliable water resource database, which can be used for conserving and managing groundwater spring zones. TVDI map calculated from imagery correlates with in-situ soil moisture measurement. Hence, the result should be applied for monitoring and evaluating moisture conditions or drought situation. Time series TVDI maps of dry months (December–March) have a consistent relation, which indicates a general situation of moisture condition. In mountainous areas, however, incorporating air temperature (Ta) and DEM in the TVDI equation will yield better results. The study provides scientific evidence to policymakers, planners and practitioners.

Cultural context is important in resource-dependent society and diversity on household water management provides evidence for the importance of cultural-specific examination. Geographic proximity is a context-specific indicator of water accessibility that exacerbates women's workload and physical strain. Geographic proximity to water source determines the outlook of local people on climate change impact on water supply. The most distinctive characteristic of water management is that it involves men and women as individual, household and community and thus requires as much attention to human behaviour as to infrastructure and technology. Hence, sensitization, besides awareness at all levels, is an indispensable attitudinal motivational capacity for climate change adaptation.

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LARGE FRESHWATER BIVALVE SPECIES: ARE THEY REALLY HEADING TOWARD EXTINCTION?: A CASE OF NATURAL LAKES OF KAILALI DISTRICT, FAR WEST NEPAL

Prem Bahadur Budha[1], Dammar Singh Pujara[1]

Executive Summary

Large freshwater mussels *Lamellidens* spp. (*Sippi* in Nepali) are long-lived molluscs. They survive for 30-130 years. They are the most important component of freshwater ecosystem because they provide a resource link between freshwater pelagic and benthic habitats, rehabilitation of organically polluted waters and provide food for many fish species and wetland birds and other vertebrates, including human beings. They are dependent on native fish host to complete early larval (glochidia) development in the gills of fishes and are the most threatened species across the world due to habitat loss.

Kailali district in Far West Nepal contains one of the highest numbers of lakes in the Terai region of Nepal. Lakes are the most important habitat for freshwater fauna. More than 100 temporary and permanent lakes in the study area were surveyed. Lake areas were measured between 1977 and 2015 through Landsat images, LRMP map and Topo map. The area of visible lakes in the Landsat images and Google Earth from 1977 to 2015 showed a significant increase in the number of lakes (167%) and total lake area (14%). The increase is due to damming for fish farming. Many lakes in the area are said to be rich freshwater fauna, but now only a few individuals of large bivalves of old age remain. Unmanaged commercialization of natural lakes into fish farming system destroys their natural substratum and natural vegetation in the lakes of Kailali district. Some large lakes have been flooded and now converted into agricultural land due to climate change anthropogenic activities. The Puraina Lake (52 ha) of Himmatpur, Bhajani-Trishakti Municipality is a prominent example. There is no sign of natural lakes at this site due to floods on the Mohana River at Nepal–India border. Some of the permanent lakes have been drying due to climate change. Evidence of climate change has been recorded in Kailali. Maximum temperature over the last thirty-nine years has increased by 0.8°C and minimum temperature has decreased by 0.3°C. Relative humidity has also been decreasing around 7%. There is a change in the rainfall pattern. The forest area has decreased by 23% from 1977 to 2015, whereas agricultural land has increased by 26% during the same period. These climatic changes, including anthropogenic disturbances (eg drying out of the lake, use of agricultural lime, mustard pellets, urea, ploughing the lake substratum), remove the native host fish, which ultimately leads large bivalves towards extinction. There is the last remaining population of old aged *Lamellidens jenkinsianus* in the natural lakes. Unless the habitat is restored and fish farming is done without disturbing their habitat, freshwater bivalves will become extinct from the natural lake system.

Context and Importance

Large-sized freshwater bivalves belong to the order Unionoida and called as freshwater mussels (*Sippi* in Nepali). They are very long-living (30–130 years) invertebrates (Bauer, 1992). Their shells have laterally compressed two valves which are hinged together by a ligament. They need to complete their early larval (glochidia) development in the gills of specific fish host to continue their generation. Mussels play an important role in the aquatic ecosystem, that is they provide a resource link between freshwater pelagic and benthic habitats (Allen and Vaughn, 2011); play a role in the rehabilitation of organically polluted waters (Erwin, 2009); provide food for many fish species, birds and other vertebrates, including human beings (Subba Rao, 1989, Ramakrishna, *et al*., 2007); and many migratory bird species depend on availability of freshwater molluscs. They are key sources of protein to many low-income ethnic human populations in many parts of the world, including the Indian sub-continent (Subba Rao, 1989, Ramakrishna, *et al*., 2007) and are also used for medical purposes (Dey, 2008). They

[1] Central Department of Zoology, Tribhuvan University

are also considered as a bioindicator of an ecosystem (Grabarkiewicz and Davis, 2008; Choubisa and Sheikh, 2013). Freshwater bivalves are globally threatened due to habitat deterioration and, in some cases, through direct exploitation (Lydeard, *et al*., 2004). Downing, *et al*., (2010) identified seventeen major causes of declining and extirpation of freshwater mussel species with more than 75% role of habitat alteration or destruction due to pollution, damming, hydrologic change, watershed change, riparian destruction, and recreational disturbance. The population and community influences of freshwater mussels were noticed by the 1990s (Stansbery, 1970). Due to rare host fish, competition from exotics, large-scale environmental changes, viz climate change, dams, impoundments, riparian destruction, agriculturalization of watersheds), and direct exploitation by humans were frequently cited as the causes of freshwater mussel extirpation (Bogan, 1993; Downing, *et al*., 2010).

There are eighteen species of large freshwater bivalve species belonging to three genera, *Parreysia, Radiatula* and *Lamellidens* reported from Nepal. Overexploitation of natural resources, particularly freshwater lakes for commercial fish farming, lead to the extinction of local fish hosts in natural systems. The evidences of declining population of native fish species were already documented in the Indrasarobar Reservoir, Kulekhani and Phewa Lake, Pokhara (Swar and Gurung, 1988; Swar, 1992; Husen, 2014) due to commercial fish farming. Fish poisoning, intentional drying out of the lake, unmanaged fish farming are the major causes of declining of mollusc population in natural lakes of the Kailali district (Budha, 2016).

This study surveyed the permanent and temporary lakes of Ghodaghodi and Bhajani-Trishakti Municipalities and associated VDCs, Pahalmanpur, Kotatulsipur and Bauniya, in Kailali district. This area has one of the highest concentrations of natural lakes in the Terai region, which include the Ghodaghodi Lake, the Ramsar sites. The commercialization of natural lakes for fish farming leads to the extinction of local host fish species, which are essential to grow larval glochidia for their survival. But data on host fish species and their relationship about which fish species are utilized by which unionoid species are extremely lacking. This paper focuses on species diversity of freshwater mussel present in different lakes, and highlights their relative population status over the last four decades. The research outcome will be used for the restoration of wetlands habitats by policymakers, planners, conservationists as well as researchers.

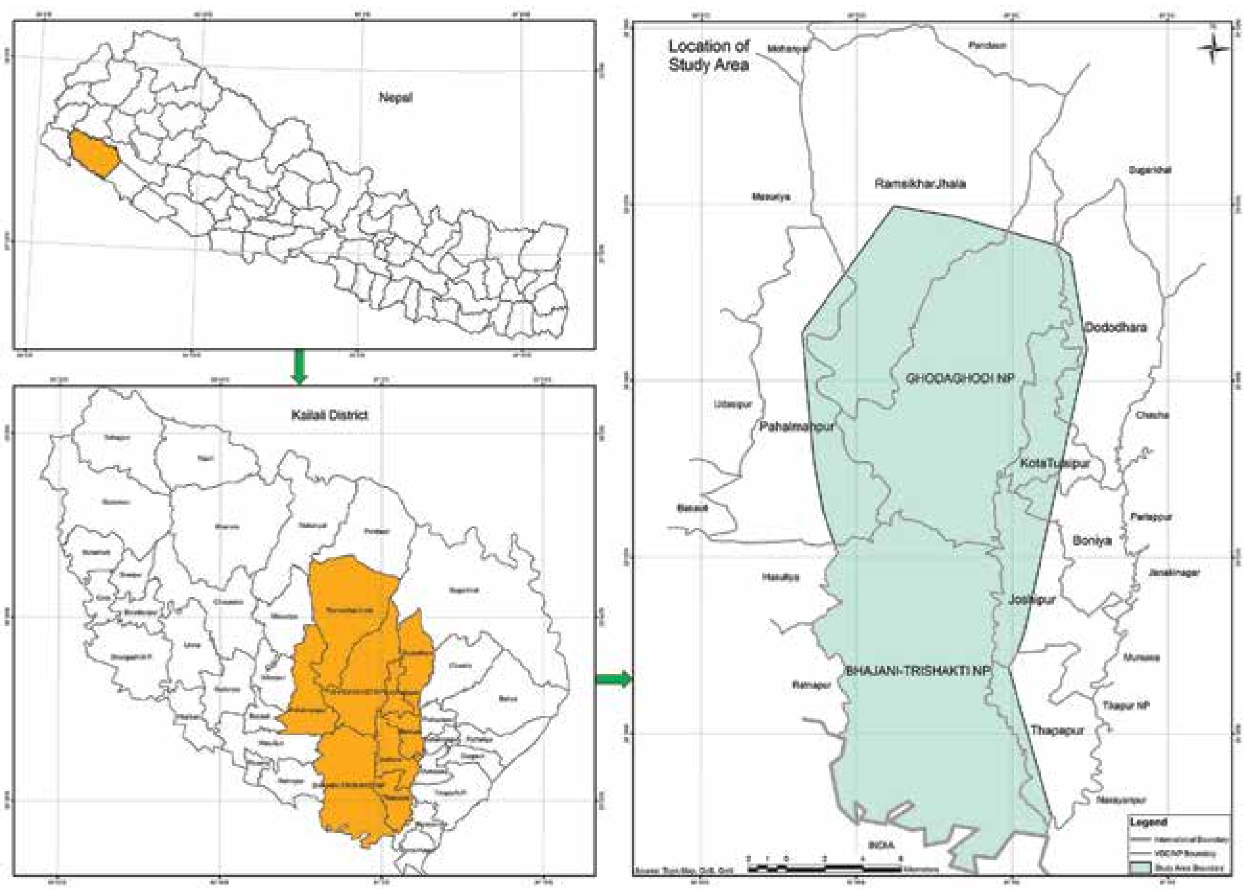

Figure 1. Location map of the study area

Methods

The study was conducted from April 2015 to May 2016. The study area is shown in Figure 1. Freshwater molluscs were sampled in different lakes and a structured questionnaire was prepared for key resource persons such as *Badghar, Bhalmansa*, fish contractors, school management committee members, lake guards and persons met at the lake, river, stream site collecting aquatic resources, fishing persons, and snail collectors during the survey period. GPS locality data taken during the field were inserted into the Google Earth satellite images from Google Earth Proto locate proper named ponds/lakes. Lake area, including river beds (including water and sand banks), agricultural and forest area, was measured as reference and land use changes over a ten-year interval from 1977 to 2015 was estimated by using downloaded Landsat Satellite Images from http://glovis.usgs.gov.

Research Findings

The lake area was measured from 1977 to 2015 through Landsat images, LRMP map and Google Earth map 2015. The area of visible lakes in the Landsat images and Google Earth from 1977 to 2015 showed a significant increase in the number of lakes (167%) and size (14%). This is due to invisible small lakes in the Landsat images, which are clearly pointed in the Google Earth map. Another reason might be damming of lakes for commercial fish farming purposes. All the surveyed lakes had very low number of large bivalve species. Only two species of large freshwater bivalves, *Parreysia favidens* and *Lamellidens jenkinsianus,* were reported from the study area. Former species was found in certain locations of slow-moving rivers, irrigation canals in sandy/muddy bottoms with rich submerged vegetation where fish poisoning practices were controlled by the local people, particularly Maghi Khola and Bauniya. That *Lamellidens* is larger than *Parreysia* was reported only from a few lakes, viz Machhrihawa, Kolkatla, Dhongrahuwa, Ghodtal and Laukabhoka (Figure 2). They were absent in most of the lakes. Both species were absent in the main rivers of the study area such as Kanara and Kanda due to high sedimentation from Churiya and regular flood destroys the permanent bottom substratum every year. *Lamellidens* are rare and their population was extremely low and only limited to the long-aged individuals only. Only a few juvenile shells were found outside the Changan Pahala Lake in small ditches at the outlet of the lake where local fishes, tadpoles and leeches were seen (see red circle in Figure 2). The tentative age of collected large bivalve shells was more than 50-80 years, based on the enumerating of growth-rings over the shell surface, which are most often used method for freshwater mussels (Neves and Moyer, 1988). Most of the respondents informed the absence of large bivalves in the lakes, but the existence of few old-aged individuals indicates that *Lamellidens* were present in the past and their population has been seriously declining. During the questionnaire survey, 92% of the informants attributed the declining of mollusc population in the area during the few decades to the use of fertilizers and poisoning of rivers and lakes. Climate change evidences have been recorded in Kailali. Maximum temperature over the last thirty-nine years has increased by 0.8°C and minimum temperature has decreased by 0.3°C. Relative humidity also decreased around 7%. There is a change in the rainfall pattern, too. The forest area has decreased by 23% and agricultural land has increased by 26% from 1977 to 2015. The climate change, along with anthropogenic activities, has led the bivalve population towards extinction.

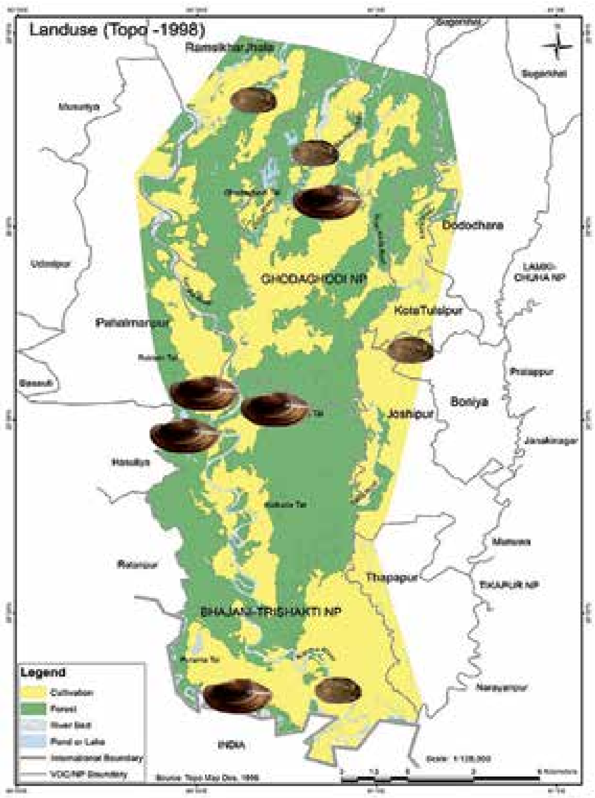

Figure 2. Distribution map of large freshwater bivalves. Large species indicated in the map is *Lamellidens jenkinsianus* and smaller species is *Parreysia favidens.* Red circle is the location from where juvenile mussels were found.

Recommendations

Nepal has shown its commitment to wetlands conservation, especially the conservation of waterfowl habitats of international importance, by signing the Ramsar Convention 1971. The Government of Nepal approved the Wetland Policy 2003 for planned conservation, maintenance and development of the country's wetlands. The commitment also includes providing support to economic, social and cultural development of local communities by improving their living conditions through wise use of these wetlands. Article 7.5 mentions about conserving the flora and fauna without allowing misuse or overuse of wetland resources. Article 6.7 regulates and systematizes the wise and sustainable use of wetland resources, along with the protection of genetic resources, conservation of animals, creatures and birds that are dependent on wetlands. The Aquatic Conservation Act (2017) prohibits the killing and trapping of aquatic life, prohibits the closing or demolishing the doors of fish ladder, dyke or any kind of structure placed in the water, and restricts the introduction of poison and explosive substances in water bodies for any type of use. The provisions of prohibition of using poison and animal movement in Articles 5A and 5B are particularly focused on fish species, which need to be focused on imperiled bivalve species and their native host fishes. Actual practice is different from these policiy commitments. Most of the regulatory acts are either neglected or not followed at public level due to the lack of proper dissemination of these Acts at public and local government levels. There are other Acts such as the Pesticide Act 1991, Water Resource Act 1992 and the Environment Protection Act 1997, which are indirectly related to freshwater bivalves, but they should be harmonized for the imperilled fauna, particularly the declining species of freshwater bivalves. Policy intervention is the most critical aspect in this respect. Acts, regulations and guidelines regarding bivalves, which are highly neglected, should be formulated. Although the provisions about the conservation of native flora and fauna are mentioned in an agreement between fish contractors and local government authorities, proper monitoring is lacking as regards whether the water users groups/individuals are following the rules and regulations. Provisions in Acts, regulations and guidelines should be disseminated at the local level. Strategies for freshwater habitat restoration programmes are highly recommended for threatened freshwater bivalve species.

Future Research

Altogether 114 lakes were documented from Kailali district by Buju, *et al*., (2010). But many lakes from the study area were missing in the list and further documentation of the temporary and permanent lakes are highly recommended. Out of about 100 lakes, only two are in the natural state and rest of the lakes are heavily exploited by unmanaged fish farming by individual contractors, community forest users groups and local users. These lakes have been drying intentionally by pumping water during dry season to harvest all fishes available in the lake. Most of the natural lakes in Kailali district are no more in the natural state due to these activities except Ghodaghodi and Nakrod lakes. This practice leads towards the extinction of native fish fauna, which are an important host for bivalve species. There is, however, severe lack of data on what bivalve species depend on what type of local fish host. Relationship of bivalve species and their fish host and their habitat requirement is an urgent need to generate baseline data for the conservation efforts and habitat restoration of both native host fish and bivalve species. Further study of the current practices of fish farming and their impacts on bivalve species is also needed. Similarly, different bivalve species are found in different microhabitats such as paddy fields, irrigation canals, slow moving streams and lakes. Their distribution pattern and the effects of siltation on the freshwater molluscs fauna are also important issues to study in the future. Genetic study (phylogenetic as well as population) of freshwater molluscs is also a burning subject for the future study.

Conclusion

The study area has shown a climate change pattern with maximum temperature increasing by 0.8°C and minimum temperature decreasing by 0.3°C and relative humidity decreasing by 7% over the last thirty-eight years (from 1976 to 2014). The rainfall pattern has changed. Forest area has decreased by 23% and agricultural land has increased by 26%. There is also change in wetland areas, the important habitats for bivalves, viz lake/pond and river bed area. Large freshwater bivalves are globally threatened and their population is declining all over the world, including in the study area, due to anthropogenic activities and climate change. Deterioration of habitat due to overexploitation of water resources and unmanaged fish farming are the leading causes of their population decline. There are very few species existing with extremely rare population of old-aged individuals. Unless the restoration of habitat and regulatory mechanisms are implemented they will become extinct from all lakes of Kailai district in the near future.

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CHARACTERIZATION OF MICROORGANISMS FOR PRODUCTION OF BIOETHANOL FROM AGRICULTURE WASTES AND USING IT AS BIOFUEL

Bhupal Govinda Shrestha[1], Binayak Raj Pandey[1], Eileen Shrestha[1], Sanjay Ghimire[1], Shaken Bhhattarai[1]

Executive Summary

Fossil fuel as a source of energy to run motor vehicles has been used widely because they easily generate energy; however, they have direct impact on the environment. Their combustion leads to a great deal of air pollution and contributes to global warming and is the cause of acid rain. Furthermore, being a non-renewable source of energy, the fear of its exhaustion persists.

Microorganism were isolated, which shows both cellulolytic and xylanolytic activities. The pre-treatment process has been optimized. Furthermore, the substrate is fermented to ethanol. Although we have not been able to make ethanol on large scale or n economically viable quantity, as of now, the efforts we put in and the results we will be able to generate will be a milestone in the global efforts to reduce the cost of bioethanol production. Genetic engineering of yeast will also be done so that it can utilize both 5 and 6 carbon sugar. Upscaling into 1L fermenter has been done.

The end result will be reduction in greenhouse gases mainly carbon dioxide and thus mitigation of the adverse changes made by climate change, through sequestering of carbon dioxide and reducing the usage of fossil fuel.

Context and Importance

At present, about 18,000 m^3 ethanol can be annually produced in Nepal from the by-product of sugar production. It has been estimated that the ethanol produced within the country can replace as much as 14% of gasoline import if 15-20% ethanol blend is used. Currently Nepal Oil Corporation is supplying 10% ethanol blends in the Kathmandu Valley.

In order to lead Nepal in the direction of self-sustainability and improved socioeconomic status of people, urgent actions are required to utilize substances like agricultural waste, which will reduce overexploitation of forest resources, as well as change conventional use of food crops for biofuel production. Using agricultural waste like sugarcane bagasse, grasses, leaves, etc. to produce bioethanol through proper research and technologies can mitigate the energy crisis in Nepal. Thus, the end result of the project will be reduced greenhouse gases, mainly carbon dioxide and thus mitigation in the adverse effects of climate change, through sequestering of carbon dioxide and reduced usage of fossil fuel.

Research Findings

The project has isolated native microorganism, which showed both cellulolytic and xylanolytic activities. Identification of the strain was done by 16s rRNA full sequencing. Similarly, glucose and xylose utilizing yeasts were isolated and used for fermentation to ethanol.

The pre-treatment process for substrate accessibility has also been optimized. Furthermore, we have fermented our substrate to ethanol. We have successfully produced bioethanol at a viable quantity on labscale and efforts are being made for producing economically viable quantities of ethanol on large scale. As of now, the efforts we put in and the results we will be able to generate will be milestones in the global efforts at reducing the cost of bioethanol production. Genetic engineering of yeast will also be done so that it can utilize both 5 and 6 carbon sugar. Upscaling into 1 L fermenter has been performed and that in 5L is being done. Finally, a seminar will be organized to disseminate the results of the findings.

[1] Department of Biotechnology, Kathmandu University

We used grass, leaf straw, weeds, bagasse and corn stover as Lignocellulosic biomass. Lignocellulosic biomass is composed mainly of cellulose, hemicelluloses and lignin. These materials, rich in cellulose and hemicelluloses, can be converted to simpler carbohydrates by saccharification and then to ethanol by further fermentation. After applying the optimal conditions and parameters, there was increase in alcohol yield up to 2.7% from 1.61%. Upscaling of up to 1L volume was done.

Two processing options were employed to produce fermentable sugars from Lignocellulosic biomass. One approach utilizes acid, alkaline, steam hydrolysis to break down the complex carbohydrates into simple sugars. An alternative method is enzymatic hydrolysis through enzyme produced from bacterial samples.

Focus now is being given to genetic engineering of yeast so that it can utilize both glucose and xylose during fermentation. This will help to increase the yield of alcohol.

Different parameters of fermentation were employed, like different concentration of yeast, 1×10^6 cell/ml to 3×10^6 cell/ml (preferably, 2×10^6 cell/ml), temperature range from 25-40° C, preferably 30° C, pH range 4-8, preferably 6, and fermentation under anaerobic conditions, to obtain the maximum yield of ethanol.

Aliquots of the fermentation liquid before and after fermentation were taken to determine glucose, xylose and alcohol. The production of alcohol then was measured with potassium dichromate method and alcohol meter. After distillation alcohol content was measured using specific gravity method. Monitoring was done through observation of plates, photos and data.

Methods

1. Microbial strains were selected from different sources as shown in Annex 1.
2. Three different broths were prepared, viz TSB, NB and Gelatine. Then, microbes were cultured in all three broths.
3. Microbes from above broths were done streaking in their respective agar media. Agar media was prepared by adding 1.5% Agar-Agar in the above broth composition. The growth quality was noted.
4. Then, microbes were characterized using congo-red media and 16s full RNA Sequencing was done from Macrogen, Inc. (Korea).
5. Hydrolysis capacity was monitored for individual microbes in all three agar media.
6. Cellulosic enzyme essay was done for all the bacteria.
7. Alcohol essay was done for all the samples in pure cellulose without optimization.
8. Optimization was done at 100 rpm and pH 7.0 for all the samples by taking sugarcane bagasse and pre-treating with 4% H_2SO_4.
9. Upscaling was done for the fermentation process in 1 L and 5 L.
10. Genetic engineering is going on for the development of yeast that can ferment both Xylose and Glucose.

Recommendations

Climate change is a phenomenon universally accepted by all sections of society and taking place the world over. It is assumed that the impacts of climate change would be of grave if we do not start to act on it as soon as possible. Carbon dioxide (CO_2) is the primary greenhouse gas emitted through human activities leading to global warming. Of the totally emitted greenhouse gases, 82% is CO_2. CO_2 emissions, therefore, are the most important cause of global warming. CO_2 is inevitably created by burning fuels like oil, natural gas, diesel and petrol. The most effective way to reduce CO_2 emissions is to reduce fossil fuel consumption and find a way to sequester it. Producing and using bioethanol as a transportation fuel can help reduce CO_2 build-up in two important ways: by displacing the use of fossil fuels and by recycling the CO_2 that is released when it is combusted as fuel. By using bioethanol instead of fossil fuels, the emissions resulting from fossil fuel use are avoided and the CO_2 content of fossil fuels is allowed to remain in storage. Further CO_2 reductions occur because the plants and trees that serve as feedstock for bioethanol require CO_2 to grow, and they absorb what they need from the atmosphere. Thus, much or all of the CO_2 released when biomass is converted into a biofuel and burned in automobile engines is recaptured when new biomass is grown to produce more biofuels.

Renewable source of energy that runs on zero carbon cycle makes a viable alternative. Agricultural waste, which sequesters carbon dioxide while growing, is largely an untapped resource. Agricultural waste or biomass is a renewable energy source that can be used as a fuel for industrial production.

Lignocellulosic biomass, the most abundant of biomass in the biosphere, is a promising alternative source of energy, which can be utilized to produce ethanol and which can replace gasoline at 10% level, for use in vehicle, without much change in the existing engine. This also helps to save on food items, which otherwise are being used to make ethanol, leading to food scarcity. The main challenge to this is efficient conversion of the complex carbohydrate into simple sugars that can be fermented to alcohol or ethanol. Ethanol can blend with gasoline and run as neat alcohol in dedicated engines taking advantage of high octane number and heat of vaporization.

Nepal has no reserves of fossil fuels and heavily depends on neighbouring countries like India for supply of fossil-based energy source. Besides that Nepal is heavily dependent on biomass for meeting its energy demands. Yet, there is a lack of integrated policy on bioenergy/biofuels in Nepal. Since bioenergy-related activities are taken care of by the different ministries and no single ministry has been assigned for this specific purpose. This fragmentation of responsibilities often leads to overlapping of mandate and roles. A policy should be adopted to decrease the share of traditional energy; promote the technologies that improve the efficiency of biomass; exploit the potential of bioenergy; promote emerging biomass conversion technologies, including gasifiers, liquid biofuels, cogeneration and briquettes.

Results from experimental labwork and upscaling up to 1L have showed that we can produce viable quantities of ethanol from cellulosic biomass. Research findings also led us to conclude that optimization in substrate Pre-treatment, Hydrolysis and Fermentation will not increase the yield of ethanol production but also production at economically viable rate. We have plenty of resources and R&D opportunities to carry out further research and bring the research results; to run it on industrial scale proper policy is inevitable.

As we do not have a clear policy on this sector yet, we immediately need to have integrated policy on bioenergy/biofuels. Responsibilities and rights should be given to one particular ministry in order to avoid unnecessary overlapping of mandate and roles. Step to commercialization of bioethanol through policymaking would be automatically making contribution to mitigate global climate change effects.

It has become important to look at the possibilities and then the capabilities of the bioethanol industry in the long-term. The policy should be made on the basis of technology options to be supported by governmental funds over the next several decades. In order to develop mature technology and see projection of our plan, R&D for conversion technology would have to occur at a much more aggressive pace than is currently being done if there is to be any possibilities of ever-seeing these projections come to fruition.

Conclusion

Thus, this project focused on different aspects of bioethanol production from agricultural waste. Various optimization measures have been carried out, which have shown increment in alcohol production. A defined media has been tested for better cellulosic activity, and this has led to a fast track for future analysis of the cellulolytic microbes in the laboratories of Nepal. These kinds of project will help to utilize the agricultural waste in Nepal for bioethanol production, which will certainly help to conserve the environment by reducing carbon emission through imported petroleum products.

All in all, special focus should be given to proper policymaking, Responsibility should be delegated to one ministry, facilitation done and funding mobilized for technological improvement and subsidy for continuation of bioethanol industry.

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RENEWABLE ENERGY: A PANACEA FOR CLIMATE CHANGE AND ENERGY CRISIS

Prabal Sapkota[1] Aastha Dahal[2], Asmita Dahal[2]

Executive Summary

Development of renewable energy resources not only generates useful energy but also aids in climate change mitigation. Energy development in Nepal has always been slow. Although multiple renewable energy resources are available, due to low economy all types of energy system cannot be developed in parallel. The government seems to be perplexed in choosing the best among the alternatives as all alternatives seem to be important and feasible. It becomes very important to prioritize them based on people's needs, resource availability, technical capability and environment-friendliness. Furthermore, it is also crucial to identify all the influencing actors that have major impacts on the development of energy systems in Nepal.

The findings of the research show that, in Nepal, policymakers should take the responsibility of energy development, followed by local people and politicians. Furthermore, the results also show that the current need for renewable energy is for the lighting purpose in the form of Photovoltaic (solar). The respondents chose biogas as the second choice of energy resource.

Nepalese government should incorporate renewable energy and climate change mitigation together. Cutting down on the subsidy in fossil fuel is the best way to encourage the development of renewable energy.

Context and Importance

Climate change refers to any substantial change in measures of climate (temperature) lasting for an extended period. Climate change may result from natural factors and processes or from human activities. Global warming refers to an average increase in the temperature of the atmosphere near the earth's surface. Global warming is one aspect of global climate change and a very important one.

Most climatic changes are the result of minor changes in the earth's orbit that affect the amount of solar radiation received by the earth. In the last 100 years, the average global temperature has risen by about 0.83°C. This rate is greater than anything observed in the past 1,300 years. For developing countries with poor economies and weak socioeconomic structures, climatic phenomena have especially grave consequences like drought and floods.

Two options are available for the human beings to deal with the climate change. The first is to mitigate climate change, which could be possible by discouraging the use of fossil fuel and developing other alternative sources which have lower impact on climate change. The other way is to adopt technologies which could capture these greenhouse gases and convert them to some useful energy or to some other less harmful products.

In developing countries like Nepal, fossil fuel, which is considered responsible for GHG emissions, comes in the form of vehicle fuel, cooking gas and industries. GHG emission in Nepal from energy use in residential sector was found to be highest (71%), followed by transportation and industry in 2000/01.Though Nepal is not a major contributor to climate change, it cannot avoid the possible consequences of climate change. Apart from that, Nepal is already facing huge problems of air pollution primarily in the Kathmandu Valley, and this condition can easily spread to nearby areas. Furthermore, Nepal is among the least performing

1 School of Engineering, Kathmandu University
2 Kathmandu Engineering College

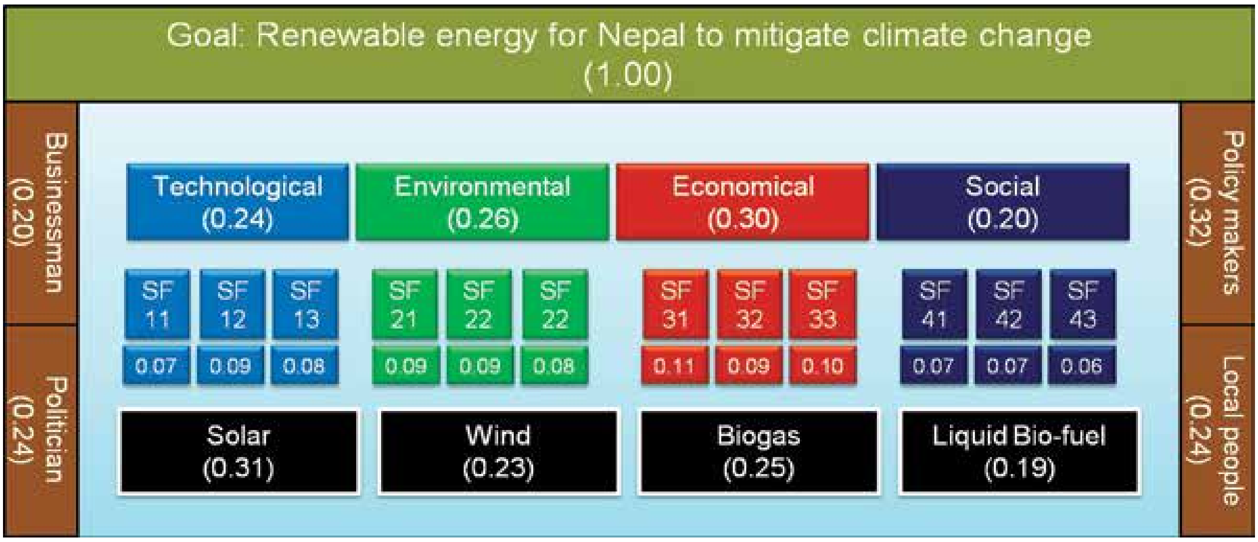

Figure 1: Overall results from all sites incorporated with the AHP model

nations in Environmental Performance Index. This suggests that the time has come for Nepal to act smoothly in various areas including air pollution and climate change.

It becomes very important for developing countries like Nepal to adopt possible measures, which could not only mitigate climate change but also honour its commitment to contribute to climate change mitigation as per the agreement signed along with 196 countries in 2015. Nepal can mitigate climate change basically by shifting its paradigm of energy use from fossil fuel to renewable energy. Energy in various forms is in practice in Nepal. People use Liquefied Petroleum Gas (LPG) for cooking purpose in urban areas. Petrol, diesel, LPG and electricity are being used in vehicles and electricity for lighting homes and work places. Similarly, coal is being used by small industries like brick industry.

Research Findings

A combined result has been obtained from the total of 976 responses to the questionnaire on renewable energy. This result is shown in hierarchical form in figure 1. The goal is at the top position with value 1.00. At the second level, four factors associated with the development of environment-friendly renewable energy systems are placed. Economic factors, with 0.30, is thought to be most important, followed by environmental, with 0.26. Technological and social issues are the third and fourth priorities, with 0.24 and 0.20 values respectively out of the maximum possible 1.00. Regarding the identification of the sub-factors, which are placed at the level 3 of the hierarchy, sub-factor initial investment based on the factor 'economic' received the highest priority of 0.11 among all sub-factors. Regarding environment as a factor, sub-factors greenhouse gas emission (GHG) and Land use (LU) received 0.09 each.

Among the alternatives which are located at the fourth level of the hierarchy, solar is preferred by the respondents as the most important among all four alternatives, with 0.31 value out of maximum possible 1.00. The second alternative preferred based on pair-wise comparison is biogas, which has value of 0.25. Similarly, wind and liquid bio-fuel are preferred as the third and fourth alternatives respectively. The values obtained for these alternatives are 0.23 and 0.19 respectively.

According to the collective responses received, among the four major actors (stakeholders) responsible for the development of renewable energy technologies in Nepal to mitigate climate change, the highest priority has been given to policymakers (0.32), followed by politicians and local people with equal preference (0.24) and the business people is given the least priority among all stakeholders.

Methods

The research work has been designed basically to identify energy needs of general people at four sites (Jhapa, Rasuwa, Nuwakot and Kathmandu Valley), incorporating their views on energy systems, energy policy and climate change mitigation. The research work has been carried out at several steps, including field visits in stepwise manner, and major calculations have been done using the Analytical Hierarchy Process (AHP).

Initially, an online survey was conducted for the urban (educated people) and one-on-one interviews were conducted in the rural population of Jhapa district. This helped to reduce the pool of choices that can be used in further research, and also learn about the energy profile of rural population. The number of valid responses obtained during the process was 91 from the online survey and 71 from one-on-one interviews.

The second step of the research work was to identify possible factors and sub-factors that are to be considered during the development of energy projects in Nepal. Furthermore, validation of the above alternatives and actors obtained from the preliminary survey was also done based on published articles. This becomes a true case of multi-criteria decision-making where multiple factors and sub-factors need to be considered in order to select the best alternative among multiple alternatives. AHP can be a good tool to deal with such a situation. AHP has carried out the work. The second stage of data collection was done based on the pair-wise comparison format of the AHP and calculations was also done based on the AHP theory.

Recommendations

The time has come in Nepal to incorporate renewable energy and climate change together, and to develop short- and long-term plans regarding renewable energy alternative development. The framework developed in this research can be used not only to prioritize the alternatives but also to perform a risk analysis of the project. Nepal has already witnessed failure of several energy projects due to multiple reasons such as inability to identify the actual needs of the people; inability to identify stakeholders' interest and influence; inability to identify the impact of energy systems on the environment and several others. If a sustainable system is to be developed, all these issues need to be taken into account and the process needs dynamic analysis predominantly focusing on subjective issues. This model can provide good solution to the underlying issues. Although the choice of alternatives, factors and actors may change in course of time, the model will be the same and will be applicable for several years.

The research provides the result of perception of Nepalese people towards energy and climate change. Although, at present, it may not give clear data regarding climate change mitigation measures in Nepal and sources of climate change agents, one should understand the dynamics of climate change and energy use.

The trend of energy consumption in Nepal has significantly increased in the last ten years. The trend will be stiffer in the next ten years' time. The significance of this work will increase once we model climate change phenomenon through energy use. Although the impact of climate change seen in Nepal is not due to causative agents produced in Nepal, one should realize that all human activities produce agents of climate change. The number may depend on the size and economy of the nation.

Regarding the best renewable energy alternative for Nepal, the first choice rated by the respondents was Photovoltaic (solar energy), followed by biogas. The result reflects the current market trend and the scenario of the country. At present, people are facing an acute shortage of electricity and they believe that solar energy can provide them with a better solution to electricity. Their perception could be based on the solar home system. People in rural areas believe that it is the easiest way to generate electricity without any hassles and, unlike biogas, they do not have to handle animal excreta and manure, ie for them solar provides energy with minimum effort on their part.

Furthermore, the general public does not have any idea regarding the production of electricity using solar energy in megawatts. They also do not have any idea regarding technical difficulties in integrating solar energy in a grid. Similarly, health and environmental impacts associated with batteries in the case of standalone system were not taken into account by the respondents. Had the respondents made all these considerations, the result would have been different. Regarding liquid biofuel, very few of the respondents had an idea about it. Although the government is promoting some non-edible oil-generating plants like jatropa, due to lack of a policy and implementation plan, many of the projects ended only on paper.

Results of the energy use profile of the surveyed areas in Rasuwa, Nuwakot and Jhapa show that development and implementation of policy on the use of renewable energy is not working well. People are predominantly using firewood only, LPG only, and firewood and LPG combined. The two areas other than Rasuwa do not have extreme cold climate. It is possible to harness biogas with good yield for at least ten months a year. Although Jhapa has the maximum number of installed household biogas plants, as per the AEPC report, the use was found to be less among the responses received in this research.

The major source of CO2 pollution in Kathmandu is the use of fossil fuel in vehicles, use of LPG in kitchen, open disposal of organic waste, untreated waste water and smoke from brick kilns resulting from the burning of coal. Nepal should develop a strong policy on proper utilization of these waste materials to generate useful energy. Production of biogas from waste (kitchen waste, agriculture residue and animal excreta) can not only save environment by discouraging the use of fossil fuel but also is the best method to trap and use methane. Furthermore, for countries like Nepal with zero petroleum resources, policies should be developed in such a way that people are encouraged to use own resources that are not being used in the country. It is also important to cut down on the subsidies for the fossil fuel. The cost of fossil fuel does not include the environmental damage caused by the use of it; so, the cost of energy generation from renewable energy sources is always higher than that from fossil fuel. It is important for the government to remove subsidies on fossil fuels. Barriers to investing in the green economy should also be removed. The under-pricing of fossil fuels also serves as a barrier to investment in energy efficiency and renewable energy sources.

Based on the analysis of the responses of the people associated with the energy projects, it seems that energy people are less concerned about the environmental factors. They have given it the fourth priority among the factors. It becomes very important for the people associated with the energy sector to be aware of global warming and climate change. Furthermore, any system to be sustainable needs to be environment-friendly with very low emission, should consume little water and should cover significantly little geographical area.

Conclusion

The major source of greenhouse gases is fossil fuel. Due to minimum fossil fuel utilization and low industrialization, the share of developing world in producing GHG agents is less. Nepal is a country with tremendous potential in renewable energy. But the major problem is to identify the energy profile of the people and which form they believe to be the most essential among all forms of needed energies. For countries with poor economy, it becomes very important to prioritize all these criteria, alternatives and stakeholders for the system to be sustainable and risk-free.

Study has shown that policymakers should take the responsibility for the development of renewable energy to mitigate climate change, followed by politicians and local people, and business people are found to be the least responsible. Based on the respondents' perceptions, solar energy is the best form of renewable energy in Nepal, followed by biogas at the second position and wind and liquid bio-fuel at the third and fourth positions respectively. Local people from all four geographically diverse locations have good understanding of the environmental concerns and greenhouse emissions.

Time has come for Nepalese government to incorporate renewable energy and climate change mitigation. Energy from municipal waste, both liquid and solid, not only helps in solving the problem of energy crisis but also reduces greenhouse gas emissions. Furthermore, it is very important for all stakeholders to act from their side to develop renewable energy and mitigate climate change.

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AN ASSESSMENT OF ECONOMIC LOSS DUE TO WATER-INDUCED DISASTER OF THE 2013 MAHAKALI FLOOD IN DARCHULA AND ITS RELATION TO CLIMATE CHANGE

Mahendra Bahadur Gurung[1], Piyush Dahal[1], Arun Prasad Bhattarai[1], Kedar Chandra Bhatta[1] Umakanta Silwal[1],

Executive Summary

The Mahakali River in Far West Nepal is a border river with India. A huge rainfall that occurred in the mountains of far western region of Nepal and Uttarakhand of India in mid-June 2013 resulted in a devastating flood in the region and caused heavy loss of lives and property in both countries.

Studies show that, from 15 to 18 June 2013, Darchula and adjoining areas, especially the catchment area of the Mahakali River, experienced localized cloud outbursts and heavy rainfall. The available inputs from various sources suggest that the southward mid-latitude westerlies and their interactions with monsoon current caused intense rainfall and that unprecedented heavy rainfall was the major cause of disaster. The studies also show that the westerlies monsoon interaction activities gradually drifted from the northern Uttarakhand area towards eastern to western Nepal, triggering major damage in the border towns in Darchula Khalanga of both countries.

This research was carried out in the Nepal side, in Khalanga in Darchula district, where the flood had hit the most, with the assistance of Climate Change Research Grant Programme 2014 under NAST. The research focused on identifying the damage, economic assessment of the losses from the floods and assessment if the event was an outcome of the climate change.

The findings suggest that the economic value of the damage and losses caused by the 2013 Mahakali flood is more than Rs 7 billion, which is five times more than the losses presented in government records. In addition, poor preparedness and planning of local resources and infrastructures against the unexpected hydro-climatic behaviour may be the reason for the loss of this scale.

This research work has provided methods for the economic assessment of the damage and losses due to the water-induced disaster by categorizing the losses into three heads, namely Direct Losses: Individual, Direct Losses: Public and Indirect Losses, and has dealt with each category in detail for the components under each. The research has come up with formulae for economic assessment.

On the climate change front, the research has analysed the extreme events from hydro-meteorological data and has ascertained that the cloud outburst and resulting rainfall pattern of June 2013 not only matched with but also exceeded 99 percentile of the past extreme events. This tends to suggest that the event could be linked with the climate change trend that is taking place in the world. It is, however, premature to establish that the magnitude of losses was fallout of the climate change phenomenon.

This case study of the Mahakali flood of 2013 and the findings may add to the wealth of knowledge in the public domain, which may be tested and further refined to replicate the application in the economic assessment of large-scale damage at any river banks of Nepal.

Context and Importance

Floods in Nepal cause huge losses of life and property each year. In Nepal, around 1,000 people die each year due to different kinds of natural hazards and, among them, about 300 deaths occur due only to floods (NSET, 2008). According to the Ministry of Home Affairs, Government of Nepal, in the last ten years, water-induced disasters alone killed 2,141 (58%) people out of the total 3,691 losses of lives due to natural calamities. Similarly, during the recorded eight years, the loss of property is found equivalent to NRs 1,240 billions, out of which NRs 931 billions (75%) is due to water-induced disasters (Paudel, *et al*. 2013).

[1] Small Earth Nepal, Kathmandu

In mid-June 2013, unusually severe devastating flooding events occurred in the Mahakali River in western Nepal. The Mahakali River is a trans-boundary river between Nepal and India. At least 106 houses, including government buildings, were wiped out by floods and more than 2,500 people were displaced. Heavy rainfall was generated by simultaneous activation of monsoon currents from eastern and mid-latitude westerlies (Paudel, *et al*., 2013). The analysis of district-wise rainfall distribution indicates that heavy to extremely heavy rainfall (≥ 100 mm) occurred on June 16 and 17, 2013 over the western districts of Uttarakhand (Uttar Kashi, Dehradun, Haridwar, Teri, Rudraprayag and Pauri), with maximum rainfall of 370 mm reported on June 17 at Dehradun. Thereafter, the heavy rainfall belt gradually shifted eastwards across Uttarakhand. Heavy to extremely heavy rainfall was reported on June 17 and 18, 2013 over the districts in the eastern parts of Uttarakhand (Almora, Nainital, Udham Singh Nagar, Champawat, Bageshwar, Pithoragarh and Chamoli) with maximum rainfall of 280 mm reported on June 18 at Haldwani in Nainital district (Kotal, *et al*., 2014).

It was found that the preliminary estimate of the losses caused by the flood as prepared by the local government was largely based on direct losses only. Having the catchment area in both Nepal and India, rather distinctly more in India, the case study was a research of complex nature. In course of research interactions, the research team realized that the economic assessment of the losses is far more than just the estimation of direct losses incurred.

The Mahakali flood of mid-June 2013 was one of the worst disasters of the recent decade in Darchula district owing to unprecedented rainfall. The loss incurred was not only limited to the damage of property and physical infrastructures but it also expanded to indirect losses in economically broader area that included opportunities land social aspects. Accordingly, direct losses were assessed in further details for individuals and public separately. And, indirect losses were also assessed and added.

Since the study has been assessed under a certain framework, it could contribute to preparing a policy guideline in dealing with the post-disaster assessment in the future. This study has brought an insightful reflection and knowledge about the causes and consequences of floods in the region, and it has also developed a methodology about how to calculate losses due to floods.

Research Findings

The general finding of the research work is that the 2013 flood on the Mahakali River has both climatic and anthropogenic causes.

The major findings of the study are as follows:

1. The flood on the Mahakali River in 2013 caused economic losses totalling NRs 7.923 billion, which is almost five times that of the losses calculated by the local government. Local government estimated the total loss of NRs 1.623 billions.
2. The rainfall on June 18, 2013 was reported to be in the order of 220 mm in Baitadi, Nepal, and 280 mm at Haldwani, in Nainital district in Uttarakhand State, India. The high flood flow on the Mahakali River surged to 440,716 cusecs, more than 10% in excess of the high flood flow the previous year.
3. The heavy rainfall and associated peak flood in the area are attributed to the cloud outburst in Uttarakhand region of India and heavy rainfall in the adjacent areas of Nepal
4. Even though the annual total rainfall is decreasing in the region, extreme precipitation events are increasing in recent years.
5. The temperature of the study area is in increasing trend.
6. Much of the loss could have been avoided if there were an early warning system linked with the rainfall and flood phenomenon in the upstream.
7. Illegal and uncontrolled activities like extracting of the gravel, stones and sand from the river bank may be another cause of erosion during high floods.
8. Most of the local businesses were found running without registration with the authorities concerned, which made it difficult to collect authentic data about the losses and about determining who is to be compensated.
9. Local victims were not able to get loans from the local banks on government recommendation.
10. The Indian government seems to have built permanent structures to train the river and protect the settlements on their border side, whereas on Nepal side, the construction began only recently and the progress was found slow due to budget constraint.
11. Some of the settlements that had been swept away by the flood had been built in an encroached area that fell in the floodplain area of the Mahakali River.

Methods

In order to estimate the economic losses, various primary and secondary information and data were analysed by descriptive statistics, cross tabulation, test of association and statistical techniques were used for appropriate different economic methods. Principal helps from contingent valuation method (CVM), cost-benefit method (CBM) and project financing method (PFM) have been taken. The data were first analysed through frequencies, percentage, mean and standard deviation, and then cross tabulation was done by using different economic methods.

Four categories of direct losses to individuals such as of land, housing, business and industrial have been dealt in detail. Similarly, the direct losses of public importance such as pathway, road, irrigation, drinking water supply, etc have been considered. Then, indirect losses such as for environment, services, facilities, communication, etc were considered. Double summation formulae have been presented and used to estimate the economic value of the losses incurred in the form of physical damage.

Similarly, hydro-meteorological data from nearby hydro-meteorological stations and other satellite rainfall products were analysed to know the hydro-meteorological behaviour of flood events, especially the extreme events. Specifically, the rainfall intensity associated with the 95th and 99th percentile over the flood area was calculated for the period. Its spatial distribution among the data stations was calculated and analysed using satellite rainfall product for the data for the last fifteen years (1998–2012) and plotted. The spatial distribution of rainfall extremes is indicative of frequent heavy rainfall reception in the flood area in the past. Then these extreme values of rainfall were compared with the rainfall amount of the event days. Similar analysis has been performed for the temperature trend.

Recommendations

The scope area of research work related to the floods of 2013 on the Mahakali River was limited to the three adjoining areas, viz Bangabagar, Main Bazaar and Galfai of Darchula Khalanga, and that the research had limited resources and time. The research has, however, led to the findings and consequent recommendations of significance. The policy recommendations are presented from three aspects based on their significance.

1. Economic assessment methods

Despite the time and resource constraints, the research has come up with development of certain formulae for loss estimation. They are briefly presented here;

a. Direct Damage (Individual) is given by,

$$D_{Dinv=} \sum_{J=1}^{m} \sum_{i=1}^{n} (aij) \times r$$

Where, 'aij' is assets of individual damage of components, number of components n = 16, and number of respondents, r =100

b. Direct Damage (Public) is given by,

$$D_{DP} = \sum_{i=1}^{n} (ai) \times r$$

Where, 'ai' is assets of public damage of components, number of components n = 16, and number of respondents, r =100

c. Indirect Damage is given by,

$$D_{ind} = \left(\sum_{i=1}^{n} (ai) \right) \times r$$

Where 'ai' is the assets of indirect damage of the components, number of components n = 7 and respondent number, r = 100.

d. The total assets of the damage is then given by,

Total assets, $T_{cp} = D_{inv} + D_{p} + D_{ind}$

These formulae have been dealt with in detail in the main report.

These formulae should be tested for validating in further research before full application.

2. Climate change perspective

Climate change, as the name suggests, is a changing phenomenon triggered by a number of factors. The number of rising extreme precipitation events, including the event of June 2013, and the trend of rising temperature tend to suggest that the linkage of the research event with the climate change phenomenon is likely. A climate change phenomenon can easily exert impact on localized places like Darchula Khalanga. But the process, vice versa, may not be equally influencing. A number of recommendations that the policy level could consider may be presented as follows:

a. A sufficiently adequate network of hydro-meteorology stations needs to be established so that the real time database is generated continuously and in a reliable manner.

b. Since the Mahakali River is largely a border river, both the neighbouring countries, Nepal and India, should develop an integrated and coordinated mechanism for an early warning system as well as for flood forecasting and management at least for the major cities on both the banks of the river.

c. A plan for watershed protection and conservation be developed and implemented on both sides of the river.

d. In order to minimize the impact of climate change, sensitization plans about the rules and regulations need to be prepared and implemented for the locals.

3. Risk Reduction Perspective

This is an outfall of the research and not an outcome. Considering the grievances of the victim population, the slow pace of reconstruction and compensation activities and possible threat in the future, the following recommendations are presented for policy decisions:

a. Identify the floodplain zone area of the river and plan settlements accordingly, allowing sufficient waterway and flood plain to the river. This policy must be implemented strictly.

b. In its 'Objective' chapter, the Water-induced Disaster Management Policy 2015 should keep a primary clause in its objective stating "risk reduction" in addition to the "reduction of potential damage".

c. For border rivers, a special arrangement needs to be devised in the Policy requiring bi-national coordination, especially in information exchange

d. The embankment construction process should progress at sufficiently satisfactory speed to convince the people in the Nepal territory.

e. The compensation promised by the government side should be arranged in a proper manner so as to enhance the confidence of the victims and affected people in the government.

Future Research

The research team has identified the following areas for future research:

a. The techniques developed by the research team need to be validated from similar research.

b. Evaluation of direct damage into asset is relatively easy. The same is, however, not true for the indirect damage, which needs further analysis.

c. Another area of further research would be developing a correlation between the flood level, damage and the economic losses.

d. Another area would be developing a relation between the scale of damage and its impact on the GDP growth of the region and/or that of the nation.

Conclusion

The research team has arrived at the following three conclusions after the research work:

1. The extreme precipitation event in the catchment area of the Mahakali River mostly in Indian and then in Nepali territory was mainly responsible behind the Mahakali flood of 2013 that inflicted heavy economic loss to the people of Bangabagar, Central Bazaar and Galfai of Darchula Khlanga, Nepal.

2. The research work in the aftermath of the flood has shown that the estimated value of economic assessment of the loss is much more than the estimate furnished by the government sector. This difference is the result of some considerations which were not taken into account by the local government but were taken into account by the research team. This includes detailing of the direct individual and public losses, consideration of indirect losses and incorporation of market rates of the property that were lost or damaged.

3. The nature and trend of the extreme events, eg for precipitation and temperature, suggest that the linkage with the climate change phenomenon is very likely. The magnitude of damage on the banks of the river and the resulting losses, however, do invite other causal factors as well, and, therefore, these losses are not likely to be solely caused by these extreme events vis-à-vis the climate change.

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ASSESSMENT OF CLIMATE CHANGE IMPACTS ON HELAMBU SUB-WATERSHED, NEPAL

Lachana Shresthacharya[1], Rakesh Sahukhal[1], Ritavrat Joshi[1]

Executive Summary

This research project was undertaken to study the climate change-induced vulnerabilities in the Helambu sub-watershed area, mainly in water and irrigation sectors, and deduce subsequent adaptation measures applicable and influential to relevant policies in Nepal. The Helambu sub-watershed is representative of many vulnerable ecological zones of Nepal with significant importance in terms of water supply not only to the indigenous peoples but to the inhabitants of the Kathmandu Valley. The research shows vulnerability in the availability of water due to unreliability in case of spring sources, as well as the supply system. A demand–supply analysis of water sources showed that all but two mapped sources were already facing deficiencies. The research suggests coping strategies such as maintenance of spring resources, groundwater recharge and water storage systems. The results of this research can provide important information to support planning for future water availability in the Helambu region.

Context and Importance

Helambu VDC in Sindhupalchok district is a mountain community, with limited accessibility and infrastructures, but having significant water resources. Just like majority of the country's settlements, Helambu is highly dependent on climate-sensitive sectors such as agriculture, forestry and tourism (Gautam, 2010).

At national level, attempts are being made to include climate change issues in the agendas and strategies, but more recommendations for action are needed. For instance, Sustainable Development Agenda for Nepal (SDAN) contains a section on climate change which lists potential consequences for infrastructure, agriculture, drinking water, and mentions risks of GLOFs. But, consequences are not adequately recognized. However, in the Local Adaptation Plans for Action (LAPA) under the National Adaptation Programme of Action (NAPA) framework there is no clear role or responsibility and involvement of the local government in the programme.

Awareness building and consultation are the key elements for development of climate change resilience (MoEnv, 2011). Traditional knowledge and systems may not be sufficient for mountain people to cope with climate change and associated extreme climate events (MoSTE, 2012). Until now assessment and resilience development to climate change impacts on various sectors are limited to short-term studies without sustained focus on replicable strategies and local-level involvement (CDKN, 2013).

This research aimed to study climate change-induced vulnerabilities in the Helambu sub-watershed area, mainly in domestic water and irrigation sector, and deduce subsequent adaptation measures, applicable and influential to related policies in Nepal. It will make recommendations for future coping strategies.

Research Findings

Hydro meteorological analysis

From the analysis of data on rainfall trend for the past thirty years, it was observed that the total amount of precipitation was decreasing with slopes of -1.848. Similarly, the discharge data taken at the Melamchi Khola station in Helambu shows an increase in minimum discharge by 0.1%, whereas the maximum water available in the river shows decreasing trend by -1.28%, which does not seem to be significant. But, when long-term trend is analysed, it shows decrease in water available in the river eventually.

[1] Environment and Energy Research Development Centre, Kathmandu

Vulnerability assessment

The vulnerability assessment indicates that domestic water and irrigation are vulnerable, which arises from reliability of resources and supply system. This could be attributed to the dependence of people on groundwater sources and the temporary nature of laid pipelines. The pipelines are placed on the ground or hung so as to spot them easily. Furthermore, the assessment showed that majority of the local population depended on agriculture for self-sustenance. Indicators representing the climate change sensitivity included dependence of population on resources and services vulnerable to climate change impacts as well as perception of resource conditions.

Demand and supply modelling

Through discharge and demand analysis of the area, water point mapping plotted the supply of and demand for each individual source. The data represents the mentioned analysis from 2016 through 2025. Projections were made for the water sources (streams generating from the Melamchi Khola and tributaries) based on log linear trend analysis of discharge data. The average maximum monthly discharge data was used for trend analysis, which showed a decrement slope of -0.0128. This slope was used to generate projection of mapped stream sources. Simultaneously, the water demand for households depending on each source was calculated. Deficit analysis showed only two sources based in Melamchighyang currently able to provide for all the needs. The ten-year deficit projection showed one of these two sources unable to meet the demands. Hence, a critical scenario of water scarcity even to meet basic demands like domestic and irrigation system was observed, which could be attributed to earlier vulnerability issues obtained from the vulnerability framework. The population growth rate of 0.001618 till 2021 and 0.005593 from 2022 onwards was used to project the demand forecasts based on the 2011 population projection for Sindhupalchok district (CBS, 2011). With increasing population and wealth, the demand for water for irrigation, domestic uses and energy is increasing.

Methods

The research methodology can be segregated into three major sections, namely vulnerability assessment and survey design, hydro-meteorological analysis and water point mapping and demand–supply analysis. A standard vulnerability assessment framework developed by (Gain, Giupponi, & Renaud, 2012) for water resource systems in developing countries was used for vulnerability assessment for the research site. A bottom-up approach was used for vulnerability assessment framework where survey design included participatory tools and empirical field studies. A vulnerability model was adapted from (Gain, Giupponi, & Renaud, 2012), in which the vulnerability assessment was done in the water resource sector focusing on the use of water for drinking, livelihood, infrastructure, commercial and irrigation purposes.

Water point mapping was done to gather positions of available water points at the research site, supplemented by demographical, socioeconomic and technical information. A handheld Global Positioning System (GPS) unit was used to record the precise location and approximate altitude of water points associated with domestic and irrigation purposes in the study area. The data was entered into a geographical information system (GIS) and correlated with available demographic and physical data. Resources, demands, distribution and other relevant information were displayed using digital maps. A water demand and supply analysis was done for domestic and irrigation purposes based on vulnerability assessment. The data on domestic use was collected through the household survey, and the monthly variation of usage can be correlated with literature data from similar other surveys for validation. For demand for irrigation water, land holding and crop plantation data was collected from the first questionnaire survey. A water demand forecasting model was developed. Linear equation from regression was used for modelling to forecast water demand versus supply.

Recommendations

NAPA was the first comprehensive government document dedicated to climate change, which was released to the public in September 2010 (Helvetas, 2012). The NAPA document identifies well-defined short- and long-term priorities for climate change actions in Nepal. After the development of NAPA, Nepal came up with an innovative local planning process called LAPA. The GoN took a strongly community-centric approach by designing and piloting LAPA. Review of the LAPA document expressed that LAPA aims to build an integrated framework that is more bottom-up in terms of planning of adaptation needs, options and priorities (LAPA\MOE, 2012). It focuses more on local communities, local needs and issues. NAPA, LAPA and CC policies identify that VDC/municipalities are the main institutions at the grass roots level to plan and implement the CC adaptation and mitigation practices, setting a target of 80% of funds to be spent at the grass roots level. As seen in Helambu VDC, however, lack of specific government body at local level means there is a question of implementation of the CC adaptation programme, particularly for the benefit of the poor and vulnerable.

In the absence of a local governing body, there was no implementing field office. So, mechanisms for proper fund disbursement, community-level plan and devolution process was difficult to conceive. This brought the question of effective utilization of allocated budget to the poor and vulnerable at local level.

The National Climate Change Policy has not clearly identified the main agents of implementation at district and local levels, focusing on poor communities. The community-based organizations in Helambu do not fully own or effectively implement resilience activities since they are not relevant in this area. This lack of information on the roles, rights and responsibilities of the local communities in execution of adaptation activities have been addressed by prioritization of stakeholders and clearly defining their level of participation in case of the Helambu sub-watershed area in our study.

The establishment of institutional mechanisms could play an important role in planning and implementation of adaptation programmes for reducing climate risk vulnerability in mountainous communities like Helambu. Also, implementation of livelihood support programmes such as microfinance and community forestry could improve the livelihood of vulnerable communities in the area and enhance the capacity for adaptation to climate change impacts.

In terms of technological interventions, we would like to recommend the following:

- Adoption of Sloping Agriculture Land Technology (SALT) is a promising agroforestry practice suitable for their steep land to manage irrigation in water scarcity situation. Proper management of SALT technology in the slope mountain improves land condition and livelihood of the local community (LIBIRD, 2007).
- The upstream communities have potential for rainwater harvesting and conservation ponds, which could be used to change their cropping, pattern to intensive vegetables. This could increase food security and farm income.
- Settlement planning to eliminate isolation of households from already scarce resources is a necessity in the area.
- Groundwater recharge technology is another practice suitable for the area. Since the area is known for presence of spring and groundwater resources, farm ponds, check dams, percolation tanks, injection boreholes in hard rocks, siphon recharge are some options based on geomorphology of the recharge site.

Conclusion

Communities in Helambu sub-watershed have adapted traditionally based on available resources, and adaptation measures were found very limited due to water scarcity. In some cases farmers had changed their occupations to activities such as hotel business or had even migrated. The vulnerability assessment done during this study confirms immediate vulnerability issues in some aspects of key sectors (water and irrigation) like reliability in case of spring sources as well as supply system. In terms of demand situation, agricultural, domestic and animal farming demands were calculated following landholding survey and crop water requirement analysis. Population growth was used as a reference point for demand changes in the future. The discharge of measured streams was correlated with the discharge trend of the Melamchi Khola and projected for the same time period as demand. Deficit analysis shows all mapped sources except two (Sources 9 and 10) are already facing deficiencies. For example, of the studied villages, Kharchung, with its daily demand of 200,697 litres/day, had a meagre water availability of 12,050 litres/day, which is shocking to say the least. Of the major ten sources, only two sources located in Melamchighyang are currently capable of withstanding daily demands. Projections show one of these sources unable to stand the demands in the next four years. Correlated discharge data of these sources with the Melamchi Khola shows an annual decrement of 1.28%, which further compounds the issue. To help address these issues, future coping strategies include instalment of institutional mechanisms to help educate and implement counter-measures, technological intervention through implementation of groundwater recharge, cropping changes, sloping agricultural land technology and settlement planning. Identification, prioritization and role definitions of stakeholders to withhold these endeavours are also addressed in the study.

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TOWARDS CLIMATE RESILIENT HYDROPOWER PROJECTS: FINDINGS FROM THE BUDHI GANDAKI HYDROPOWER PROJECT

Khada Nanda Dulal[1], Vishnu Prasad Pandey[1], Utsav Bhattarai[1]
Rohini Devkota[1], Harshana Shrestha[1], Shrijwal Adhikari[1]

Executive Summary

Climate change (CC) may impact hydropower projects by altering energy production and posing risks to the safety of hydraulic structures. Currently, neither technological nor social aspects are being considered to enhance resilience of hydropower projects to projected climate changes. From the results of the Budhi Gandaki Hydropower Project (BGHP) case, it can be deduced that diversified technological options, including skills development, awareness and capacity building of communities is to be integrated into the development practices to reduce climate change vulnerability and risks in hydropower projects. Furthermore, to enhance resiliency of hydropower projects to climate change, it should be mainstreamed with national goals (such as water security, energy security, hydropower development, etc) and translated into actions.

Context and Important

The Hydropower Development Policy (HMG, 2001) has highlighted that there is an abundant possibility of hydropower generation in Nepal. Despite having a huge potential and setting an example of the first hydropower construction in Asia (ie Pharping hydropower, installed capacity = 500 kW), Nepal is facing a severe energy crisis for the last few decades. It is uncertain which of the identified mega hydropower projects such as Arun III (900 MW), Upper Arun (335 MW), Lower Arun (300 MW), Budhi Gandaki (1200 MW), Upper Seti (127 MW) and West Seti (750 MW) will be implemented. But given the current mere 750 MW of installed capacity, increasing energy demand, and availability of a huge potential for hydropower, a large amount of energy is expected to be generated from hydropower in mid to far future. Hydrology is a critical aspect in any hydropower project. Watershed hydrology is highly sensitive to climate change and is expected to be intensified, resulting in drier dry seasons, wetter rainy seasons, and higher frequency and intensity of extreme events with variability/ change in climate (TU, 2009). It may further result in alterations in annual energy production as well as design discharge for hydraulic structures, thus, necessitating alteration in size of the structures, which ultimately will have implications for the project cost.

Most of the recent studies generally agree that the earth's climate is changing and consequently impacting on many aspects of society and ecosystems (IPCC, 2013) in all the regions around the world. The poorest countries (such as Nepal) are likely to suffer the earliest and most from the impacts of climate change (Khajuria and Ravindranth, 2012; World Bank, 2010).

Studies related to climate change in Nepal have shown significant warming trends in the recent decades (Devkota, *et al*., 2014; Lohani, 2007) and projected to continue warming, with average mean temperature increase of 1.2°C and 3°C by 2050 and 2100, respectively (World Bank, 2009). Being a mountainous country with a wide variation in topography (from 17m to 8,848 m), climate is, however, expected to vary even within a short distance (horizontal and vertical). Therefore, it is desirable to assess the extent of climate change and associated impacts on project-by-project basis.

Given the large expected operational life of hydropower projects and sheer size of the initial investments required, it is necessary to understand the extent of climate change and their impacts, and devise strategies to enhance resiliency to climate change for sustainable production of energy. In this context, a few key questions are:

[1] Asian Institute of Technology and Management, Lalitpur

- What is the extent of climate change in the catchment above the dam site of the hydropower project?
- Whether the climate change impacts significantly to sustainability of the hydropower project?
- How can we enhance resiliency of hydropower projects to climate change?

Research Findings

The Budhi Gandaki Hydropower Project (BGHP) is one of the three hydropower projects prioritized by the GoN as the "Projects of National Pride" to address the looming energy crisis in the country, which is visualized in the form of many hours of power outage a week; disruption in social lives and businesses; and loss in the national economy. The BGHP is located in the Budhi Gandaki River Basin (BGRB, Figure 1), which originates in China and extends to Gorkha and Dhading districts, Western/Central Development Region, Nepal. The Budhi Gandaki is the main river that drains water out of the 5,005 km^2 watershed above the proposed dam site of the BGHP. During the prefeasibility stage, the project was conceptualized with an installed capacity of 600 MW generating an average annual energy of 2,495 GWh. Later, during the feasibility stage, it was proposed that the installed capacity of the project be 1,200 MW with an average annual energy generation of 3,383 GWh (BHPDC, 2015).

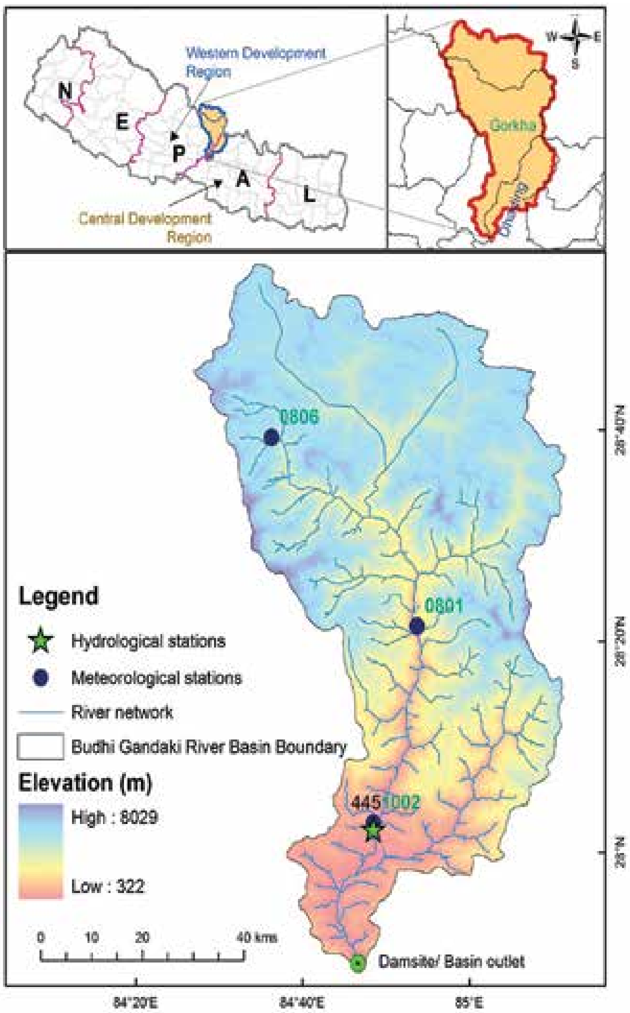

Figure 1: Location and details of Budhi Gandaki River Basin, Nepal.

Historical trends in the climatic variables suggested that upstream of the BGRB is getting wetter while the middle and down-streams are getting slightly drier. In terms of temperature, both maximum and minimum temperatures are increasing at a gentle rate from 0.02 to 0.08 °C/year. This means that the basin in general is getting hotter over the recent years. The increasing trends in precipitation and temperature are expected to continue in the future as well. Under the three RCP scenarios (ie RCP2.6, RCP4.5 and RCP8.5) and three future time windows (ie near future (2011–2041), mid-future (2042–2072), and far future (2073–2100)), the annual precipitation with respect to (w.r.t.) 1981–2005 baseline is expected to increase from +1% to 35%, and average monthly maximum and minimum temperatures from +1% to +6% and +2% to 7% respectively.

Hydrological model suggested no distinct/visible pattern of rise in the river discharge, but a slight increase in the average annual discharge and amplification in the peaks in the future. Furthermore, frequency of extreme events, mainly high floods and extremely high floods, are projected to increase, but mostly in the monsoon season. The reservoir simulation results show that if 600 MW (three units) or 1200 MW (six units) is produced during the monsoon and at least 365 MW can be generated during the dry periods. As future water availability, at least until the end of this century, is projected to increase, the estimated energy production is expected not to decrease due to change in hydrology. In addition, as the low flows in the future are expected not to change significantly w.r.t. the baseline, power production from the project during the dry season is expected not to vary much from the current estimate. The future flood discharge is expected to increase, however, proposed capacity of spillway in the current design (BHPDC, 2015) is capable of addressing future flows.

In terms of adaptation strategies, social analysis ranked technological measures as the first priority to cope with both flood and drought events; however, "natural retention of flood water" was ranked as the second in case of flood event and "increasing water use efficiency" in case of drought.

Methods

This research has conceptualized and applied an interdisciplinary hydro-sociality (please refer to the following for details of the concept: Baldassarre, *et al*., 2013; Kandasamy, *et al*., 2014; Sivapalan, *et al*., 2012) approach that integrates various state-of-the-art scientific tools such as trend analysis tool (RClimDex), hydrologic model (HEC-HMS), extreme analysis tool (IHA), reservoir simulation model (HEC-ResSim), and participatory social survey. It then assesses existence and extent of climate change, its impacts on BGHP, and possible adaptation strategies to make the project climate resilience in the long run. Historical daily data of hydro-climatic variables (ie river discharge, rainfall, maximum temperature, and minimum temperature) of the past thirty years were collected from the Department of Hydrology and Meteorology (DHM), Nepal. For the future climatic data, the latest AR5 climate projections under three Representative Concentration Pathway (RCP) scenarios (ie RCP2.6, RCP4.5 and RCP8.5) from the Canadian Earth System Model (CanESM2) GCM were used. The HEC-HMS model was calibrated/validated for the BGRB to assess CC impacts on hydrology and then in energy production and HEC-ResSim for simulating the reservoir operation. The projected future climate data was forced into the calibrated models to quantify impacts of CC. A social survey was carried out parallel in the project-affected areas to identify and prioritize workable adaptation strategies to cope with the extreme events associated with the CC.

Recommendations

Nepal needs to approach hydropower development through three strategic considerations:

- Building large-scale storage projects envisaged primarily for exporting energy;
- Medium-scale projects for meeting national needs; and
- Small-scale projects catering to the local communities.

The climate change impacts various aspects of a hydropower project and causes threat to sustainable production of energy throughout its lifetime. To make future hydropower projects climate resilient, the BGHP case study offers an integrated hydro-sociality framework to assess climate change impacts and devise workable adaptation strategies.

As future climate is projected to be wetter and warmer, leading to increased frequency and intensity of extreme events, various ranges of adaptation strategies are required to be put in place to make the hydropower project climate resilience. Though findings in this study are based on projection of future climate by a single GCM (ie CanESM2), it provides meaningful information. It is, therefore, recommended to take initiatives for mainstreaming climate change impacts and adaptation studies for hydropower project appraisal. Currently, like many other least developed countries, climate change issue has been prioritized only to the extent that is reflected in the national development objectives in relation to protection of the environment and sustainable development. Unless climate change is linked to the country's national development goals and translated into action, priorities cannot be attached to it, and hence they are not mainstreamed in any sector, including hydropower. Therefore, policies should be aligned to mainstream climate change by means of linking to the long-term development goals such as poverty reduction, economic growth and employment, increased self-reliance, promotion of rural development, and preserving the environment. To enhance resiliency to climate change, reforms in resources access to ensure no threat to human rights to resources are required.

From the results of the BGHP case, it can be deduced that diversified technological options, including skill development, awareness and capacity building of climate change-affected communities is to be integrated into the mainstream development practices to reduce climate change vulnerability and risks in hydropower projects. To ensure that the climate change impacts on water resources are addressed adequately, focus on the following aspects are required (WECS, 2011) : i) Research; ii) Optimum size of monitoring network; iii) Strong database; and iv) Action-oriented research.

Though not analysed in this case study, sedimentation characteristics under changing climate may differ significantly, thus, demanding significant change in sediment management practices. In addition, how upland–lowland and upstream–downstream linkages is expected to alter with climate change in a hydropower project needs to be studied considering a holistic approach. Strategies and plans based on scientific investigations need to be devised for enhancing resiliency of hydropower projects to climate change.

This research helps in overall policymaking by developing a framework which (1) identifies priority areas for adaptation policy interventions; (2) targets and justifies adaptation funding and programmes; and (3) uplifts the livelihood of local communities. The outcomes of this research serve as a baseline document for the implementation of the Budhi Gandaki hydropower project.

Conclusion

Climate change is evident in Nepal in the form of significant warning trends in recent decades and projected continuation of the same in the future, where mean temperature is projected to increase by 2°C by the end of this century. It may impact hydropower projects by altering energy production and pose risk to safety of hydraulic structures due to increase in frequency and intensity of extreme events.

Future climate in the catchment of Budhi Gandaki Hydropower Project is expected to be warmer and wetter, following the past trends, resulting in a slight increase in the average annual discharge and amplification in the peaks, but no reduction in energy production. Proposed capacity of spillway is adequate to cater to flood discharge under future climatic conditions. The "technological measures" is found as the high-prioritized adaptation strategies among several others to cope with the climate change impacts.

The findings of the research point to the need for a clear policy, provisions and strategies for rural people living near hydro projects that are affected by climate change. Moreover, the outcomes of this research can help policymakers review alternative climate change adaptation strategy options.

To enhance resiliency of hydropower projects to climate change, it should be mainstreamed with national goals (such as water security, energy security, hydropower development, etc) and translated into action.

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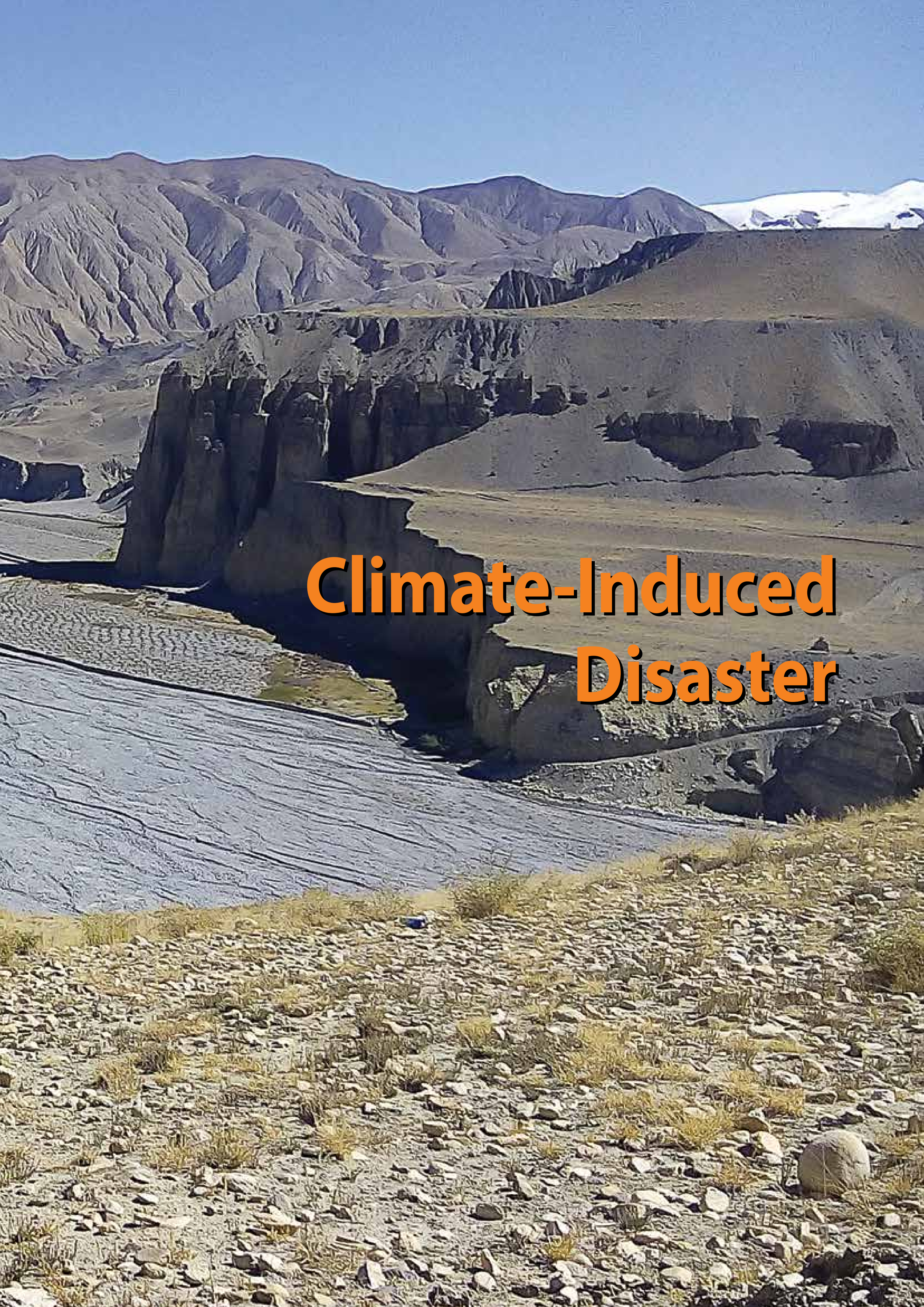
Climate-Induced Disaster



MARSYANGDI RIVER BASIN WATER-INDUCED DISASTER TRIGGERED BY CLIMATE CHANGE AND ITS PROGNOSTIC PROJECTION

Dinesh Pathak[1], Dibesh Khadka[1], Lalu Prasad Paudel[1], Manita Timsina[1]

Executive Summary

Climate change is a major global issue, and serious concerns have arisen at national and international level to assess the nature and extent of climate change at global and local/national level. The earth's climate system is changing, as evidenced by the rise in temperature, change in precipitation patterns, increase in intensity and frequency of extreme events, and acceleration in melting of snow and glacier reserves over the period. In Nepal, evidence is found in the form of increase in mean temperature, change in precipitation magnitude and pattern, and retreating of the Himalayan glaciers. The pronounced impact of climate change in the Higher Himalayas is observed in previous studies with projection of increased temperature and precipitation (WWF, 2005).

There is a tremendous problem of water-induced disasters in the Marsyangdi River Basin. Climate change will further intensify the disaster risks. Due to more extremes in monsoon rainfall, landslide hazard scenario in the basin has changed from the last twenty years and it will further change in the future.

The people living in rural areas have limited access to road, clean drinking water, and agriculture field, and, therefore, have low coping capacity. The government should target these populations so as to raise their coping capacity through mitigation, adaptation and economic enhancement. Few studies of climate change and water-induced disasters are available in Nepal to guide such policy development. This study contributes to filling that gap.

[1] Central Department of Geology, Tribhuvan University

Context and Importance

Climate change in Nepal will have effect on every sector of life from agriculture to health and shortage of water to excess of water, resulting in water-induced disaster. In order to face the problem due to climate change in various sectors, research work is required and, for this, reliable and sufficient data is needed.

Nepal has formulated a climate change policy, National Adaptation Programme of Action (NAPA) and Local Level Plan of Action (LAPA). Formulation of policy, plan and action programme is, however, not sufficient unless it is effectively materialized. The effectiveness should be observed in the rural villages where people are less capable economically, educationally and socially deprived with limited access to resources and at government level. In addition, infrastructure development in the mountainous region should also consider possible impacts due to climate change. The hydropower projects, roads and other infrastructure should be sustained even in the changed climatic conditions in the future. The increased soil loss from mountainous areas will affect agriculture, infrastructures and livelihood of the people.

Research Findings

The future climate projection for the Marsyangdi basin has been carried out using the output of CanESM2, which is downscaled, to station level using the statistical downscaling model (SDSM).

It is projected that the average precipitation in the Marshyandi basin will increase in the future under climate change scenario. The projected increase in precipitation in the future has inverse relationship with the elevation, where stations in lower elevation have higher projected increase. For RCP 2.6 (optimistic scenario), projected increase in annual average precipitation for all future period is about 3–4% compared with the baseline.

Similarly, annual average precipitation for RCP 4.5 (intermediate scenario) is projected to increase by 7%, 13% and 14% in the 2030s, 2060s and 2090s respectively. RCP 8.5 (pessimistic scenario) has highest projected increase in annual precipitation, which is by 10%, 12% and 21% in the 2030s, 2060s and 2090s respectively. In terms of extreme precipitation, 99th percentile exceedance precipitation for summer season has been considered in the analysis. In most of the stations considered, this precipitation value has been projected to increase in the future. Even in stations where annual precipitation has been projected to decrease, magnitude of the 99th percentile precipitation is projected to increase. It is an indication that, in the future, occurrence of extreme precipitation events will have higher magnitude and frequency. Compared to baseline period, the 99th percentile precipitation is projected to increase in average by 13%, 20% and 21% in the 2090s for RCP 2.6, RCP 4.5 and RCP 8.5 respectively.

For RCP 2.6, no significant increase in annual discharge in future period is projected (about 3%). While for RCP 4.5, annual average discharge is projected to increase by 5%, 8% and 9% during the 2030s, 2060s and 2090s respectively. Similarly, for RCP 8.5, annual average discharge is projected to increase by 6%, 8% and 14% in respective periods. Extreme flood discharge, which is linked to flood hazards, is projected to increase for high emission scenarios. By 2090s, the magnitude of extreme flood is projected to increase up to 12%. Projected flood discharge for climate change scenario has been fitted in HEC-RAS model to estimate the extent and depth of inundation for the Abu Khaireni area. For extreme scenario, inundation area is projected to increase by 6% and depth by about 0.6m by 2090s. Thus, the study suggests flood hazard is likely to increase in the future.

The change in precipitation scenario with more intense rainstorms due to climate change will have direct correlation to the increased water-induced disaster in the basin. All the districts (Gorkha, Lamjung, Manang) in the Marsyangdi basin will be affected from various water-induced disasters like flood and landslide. The landslide hazard map prepared for the basin with and without climate change condition shows that the central part of the basin is already a high hazard zone, which will further expand to the southern part in the future with changed precipitation conditions due to climate change.

Methods

The methodology section is presented only to show that the findings are credible/evidence-based.

The methods applied in the present study are briefly listed below:

1. **Climate modelling**
   - ***Trend analysis***

   Use of long-term observed meteorological data acquired for nine stations from the Department of Hydrology and Meteorology (DHM). Analysis of temporal and spatial variations of precipitation within the study area, along with trend analysis, was performed for the observed period.
   - ***Climate change projection***

   Second Generation Canadian Earth System Model (CanESM2) developed by Canadian Centre for Climate Modelling and Analysis (CCCma) (Salzen, *et al*., 2013; Arora, *et al*., 2011) is used. The data from CanESM2 is downscaled using the Statistical Downscaling Model (SDSM), which is then bias corrected to remove any systematic bias. The SDSM model is calibrated for 1961–1995 and validated for 1996–2005. Future climate change projection is divided into three periods: 2030s (2011–2040), 2060s (2041–2070) and 2090s (2071–2100).

2. **Hydrological Modelling**

   The long-term flow data available at Bimalnagar (station no. 439.7) in the Marsyangdi basin maintained by the DHM is used for hydrological analysis and modelling purpose. The HEC-HMS model is extensively used to simulate the discharge at the downstream of the study area (at Bimalnagar) for observed and future periods. The model is calibrated using the measured discharge data for the period 1988–2002 and validated for the period 2003–2010.

3. **Flood Hazard Assessment**

   Hydraulic modelling was carried out to determine the extent and depth of inundation during extreme floods. Hydraulic modelling was carried out for the river valley near Abu Khaireni (at downstream reach of the Marsyangdi River). This river valley is identified as vulnerable based on its proximity to riverbanks and presence of settlements. Hydraulic modelling at this reach will serve as an example and indicator of how inundation areas may change in the future under climate change scenario. HEC-RAS software was used in collaboration with ArcGIS for creating an inundation map of the area.

4. **Landslide Hazard Assessment**
   - ***Landslide Inventory***

A landslide inventory map, consisting 581 landslides, was prepared from the Google Earth images of the study area.

- ***Landslide Factors***

Slope, aspect, geology, land use, distance from river, distance from road and rainfall are the parameters considered as landslide factors.

- ***Landslide Hazard Modelling***

Various models were applied to landslide susceptibility and hazard mapping. Two approaches, namely 'information value method' and 'weight of evidence', were used to develop the landslide hazard model. The landslide hazard map was also prepared for the projected climate condition with changed precipitation condition in the future as per the model output.

Recommendations

The following recommendations that have direct links to the policy issues can be drawn:

- Marsyangdi basin will observe the climate change conditions in the future. Therefore, the policy should address this for effective implementation of mitigation and adaptation measures to cope with the changed conditions.
- Water-induced disaster will have pronounced effects on settlement, agriculture land and infrastructures. The cultivated area shows the highest landslide susceptibility index (LSI) among various land use classes. Area nearer the stream and lineament are more susceptible than others. Distance to road and distance to river also show similar trends. In this context, policy should guide urban development as well as infrastructure development along the major roadside and riverbank areas to ensure protection from water-induced disasters in case of extreme climatic events.
- It is necessary to develop a framework to convey the findings of scientific studies to the local authorities and community so that they can be well informed about what is expected to happen in the basin. It will support every activity leading towards minimizing the impact of climate change. This should be guided by policy at national level.

Future Research

The following aspects of future research are expected to be useful to minimize the disaster loss due to climatic extremities in the future:

- The research work should be a part of continuous activities. The impact of climate change and resulting water-induced disaster should continuously be monitored with an efficient database. This will be helpful to further improve the earlier research output. The present limitation of the research is availability of very limited number of station data. Better understanding of the subject-matter can be achieved once sufficient amount of reliable data is available.
- The actual damage and loss due to the water-induced disaster should be recorded and it should be correlated with climatic extremities.
- The usefulness and adequacy of the applied mitigation and adaptation measures should be re-evaluated after every event.

Conclusion

The future climate projection for the Marsyangdi basin has been carried out using the output of CanESM2. Three projected scenarios for Representative Concentration Pathways (RCPs), namely 206, 4.5 and 8.5, have been developed. It is projected that average precipitation in the Marsyangdi basin will also increase in the future under climate change scenario. It is found that the projected increase in precipitation in the future has an inverse relationship with the elevation, where stations in lower elevation have higher projected increase. Compared to baseline period, 99th percentile precipitation is projected to increase in average by 13%, 20% and 21% in the 2090s for RCP 2.6, RCP 4.5 and RCP 8.5 respectively.

The HEC-HMS model output leading towards simulation of the discharge for climate change scenario shows that, for RCP 2.6, no significant increase in annual discharge in the future period is projected (about 3%). While for RCP 4.5, annual average discharge is projected to increase by 5%, 8% and 9% during the 2030s, 2060s and 2090s respectively. Similarly, for RCP 8.5, annual average discharge is projected to increase by 6%, 8% and 14% during the respective periods. Extreme flood discharge, which is linked to flood hazard, is projected to increase for high emission scenarios. By 2090s, magnitude of extreme floods is projected to increase up to 12%. Projected flood discharge for climate change scenario was fitted to the HEC-RAS model to estimate the extent and depth of inundation for the Abu Khaireni area. For extreme scenario, inundation area is projected to increase by 6% and depth by about 0.6m by 2090s. The study suggests flood hazard is likely to increase in the future. The band of projection between RCP 2.6 and RCP 8.5 provided general range of this increment, which will be determined by socioeconomic and emission pathways in the future.

Record shows that there have been series of landslide, flood and avalanche disasters in the Marsyangdi basin. The northern part of the basin is situated in Manang district, which is not only affected by avalanches but also floods. For example, Thoche and Dharapani VDC areas were affected by floods in 1996, 2006 and 2009 (UNISDR, 2011). Similar was the case of flood disasters in Bhujung village in Lamjung and Barpak villages in Gorkha districts. Landslide is widespread in the basin. Dharapani, Chame and Bhraka villages in Manang district, Simpani, Nalma and Bahundada villages in Lamjung district and Palungtar village in Gorkha district are some of the cases that faced human casualties and destruction of houses due to landslides. These examples indicate that geo-disasters are common in the study area, which is expected to increase in the future with the pronounced climate change leading to either increased precipitation or change in nature of precipitation to low duration high intensity. The projected increased precipitation from the present climate model has been used to develop projected landslide hazard maps. It is observed that high landslide hazard areas will increase in the future. Such areas should be considered for mitigation and adaptation measures so as to cope with the adverse situation in the future, thereby, reducing the disaster risk.

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CLIMATE CHANGE IMPACT AND ADAPTATION MEASURES NEEDED IN UPPER MUSTANTG TO PREVENT MORE CLIMATE REFUGEES

Hari Krishna Shrestha[1], Suresh Prasain

Executive Summary

People in Upper Mustang, Nepal, have adjusted their lifestyle to arid environment and have been living happily for many centuries by balancing their needs with what nature has provided. They grow drought-resistant plants for food, raise drought- and cold-resistant animals for meat, and sell wild herbs for cash income. In the last few decades, due to climate change, things suddenly changed rapidly beyond their coping capacity. Agricultural production plummeted, animals began to die due to unseasonal snowfall and wild herbs disappeared. Unable to fathom why nature gradually turned against them, they changed their lifestyle by reducing farm land, selling more animals to compensate for reduced cash income, and increasing the frequency and duration of seasonal migration.

The residents of Dhye village in Upper Mustang approached the local government for assistance for many years without much success. Eventually, they realized that the environment was going to get worse with the passage of time, their elongated absence from family and community was destroying their very identity and the whole settlement was gradually collapsing, the Dhye residents unanimously decided to "leave their habitat" and resettle in Thangchung, thus becoming climate refugees. However, they are yet to prove that they are "climate refugees" and are entitled to land right in area with better water access.

This research project analysed climate data and showed direct links between the changes in climate parameters in Dhye village and its consequences, thus providing evidence of climate refugee. Formulation of proper policy on climate change and its timely implementation could have averted this unfortunate situation.

Context and Importance

Data show that climate change is impacting higher elevations at elevated rate. Life and livelihoods in many mountain settlements in Nepal are under stress from desertification, drought and water scarcity. Due to extreme climate change, the inhabitants of Samzung and Yara villages are contemplating abandoning their ancestral villages and those of Dhye village have initiated steps to resettle their community in a different location; all three villages are in Upper Mustang.

Due to paucity of long-term baseline site-specific climate data, it is often a challenge to determine the degree and trend of climate change in Nepal. The capacity of local government agencies to monitor and provide timely assistance to the people adversely affected by climate change is limited. Development and implementation of local-level policies and plan of action to increase climate resilience of vulnerable settlements are in low priority due to competing resource demand for infrastructure development. It is now, however, becoming increasingly clear that development activities without due consideration to climate change are inherently unsustainable, and inability to take preventive actions against potential climate-induced disasters is going to push vulnerable settlements into forced migration and turn them into climate refugees.

Since climate change rate is expected to exacerbate, it is extremely important to address this issue in time with higher priority, allocate adequate resources, and implement coordinated programmes to prevent more climate refugees in Nepal.

[1] Hydroknowledge System, Lalitpur

Research Findings

Due to limited livelihood options and scarce natural resources, the balance between natural environment and human settlement is very delicate in Upper Mustang area. Due to low access to water, they grow wheat, naked barley and maize, which need little water. They practise animal husbandry, mostly mountain goat, sheep, and high altitude cattle like yak that grow thick fur and can withstand severe cold and drought because they can thrive on thorny plants. The climate change has disturbed this delicate balance and life is becoming increasingly miserable in Dhye village.

Different qualitative research works in the past have indicated adverse impacts of climate changes in Upper Mustang settlements, including Dhye village. Analysis of data clearly indicated that climate parameters are changing at a rapid rate in Dhye, it is affecting biophysical and socioeconomic parameters, and impacting livelihood, social fabric and identity of the Dhye residents, as illustrated below.

To prevent complete collapse of Dhye community, all the households unanimously decided to mass migrate out of Dhye village and resettle in Thangchung, within their own wards in Surkhang VDC. As an initial resettlement step, they established an apple orchard in Tsawalhe, near Thangchung. One of the concerns of the Dhey residents is potential water stress in Thangchung in the near future; hydrological analysis of Dhye Khola assured that enough water will be available for Thangchung for a foreseeable future. They are, however, yet to convince government officials on their climate refugee status and obtain land right at the proposed resettlement area. The output of this research can serve as a basis for establishing their right as climate refugees.

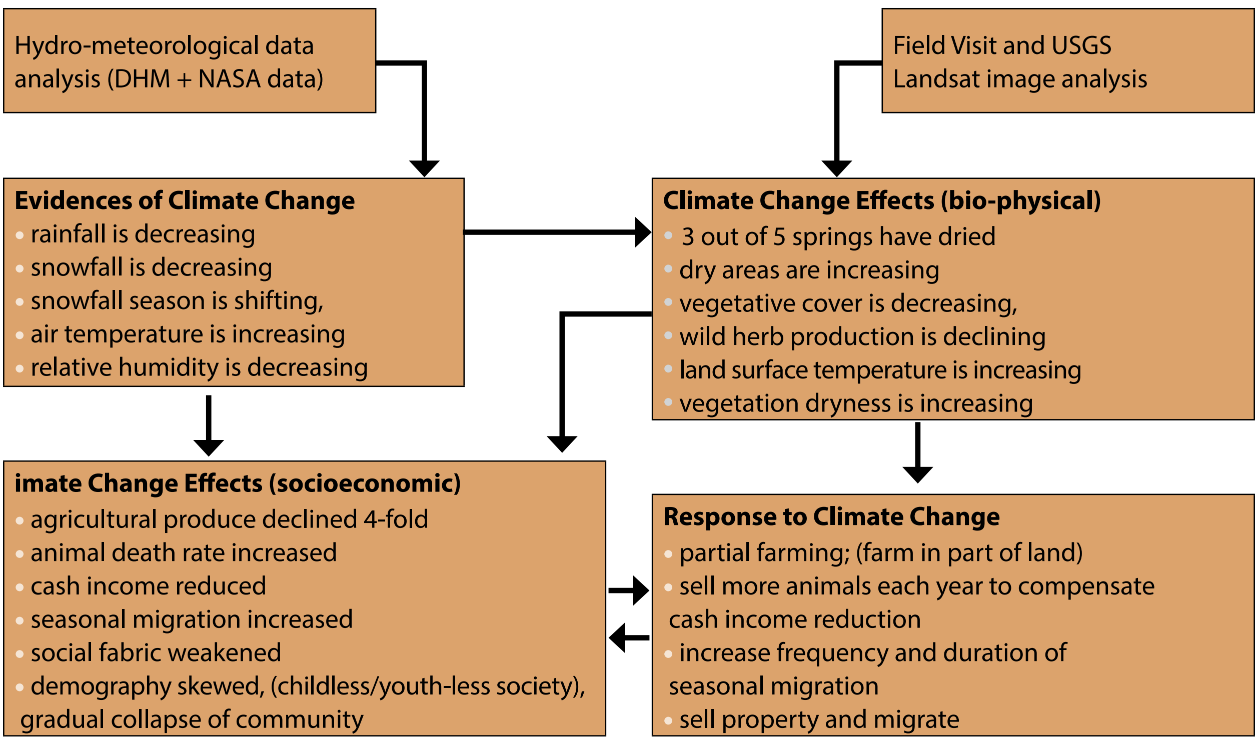
Methods

The research method followed in the CAMUM project consisted of a series of sequential and parallel steps.

Literature survey was conducted to find effects and impacts of climate change in the higher mountain settlements of Nepal and to prepare a list of data gaps and a draft questionnaire.

A consultative meeting was organized with high elevation climate change experts in Kathmandu and Dhye residents in Kathmandu to finalize questionnaire, plan timing and duration of field visit and establish link with Dhye residents.

A series of field visits were conducted to collect primary biophysical data, conduct social survey of each household, collect soil samples, measure discharge, and interact with local residents to understand climate change problems and their coping mechanism.



Secondary data from DHM and NASA were analysed to find the degree and trend of changes in climate parameters (rainfall, snowfall, air temperature, relative humidity). Hydrological analysis of Dhye Khola was conducted to determine long-term water availability for Dhye residents, if and when they resettle in Thangchung.

Location of river diversion of Dhye Khola for irrigation at Thangchung was determined and appropriate technology to lift water to Thangchung plateau was determined. Final research output was summarized in a pamphlet and distributed to stakeholders for appropriate use.

Recommendations

It is now an established fact that global climate change is occurring and accelerating; the rate of change is higher at higher elevation. Many rural and vulnerable settlements are directly affected by the changing climate beyond their coping capacity, and some of them have started to abandon their settlements and become climate refugees. To address this issue head on, the GoN approved the Climate Change Policy 2011. This comprehensive policy addresses all aspects of climate change, including research, law and institutional setup at local, regional and national levels. The need is to effectively implement the existing policy rather than developing a new one. The following policy recommendations are prepared specifically for addressing the current issues of the plight of the settlements in the Upper Mustang area, including Dhye village. These recommendations may be considered a subset of the existing national policy of Nepal.

a) The Global Governance Project defines climate refugees as "people who have to leave their habitats, immediately or in the near future, because of sudden or gradual alterations in their natural environment related to at least one of the three impacts of climate change: sea-level rise, extreme weather events, and drought and water scarcity". The Climate Change Policy 2011 of Nepal lists strategy to reduce hazard, vulnerability and risk of communities associated with climate change, but it is silent on climate refugee. Legal and administrative changes to verify climate refugee and establish their right to resettle at a different location with land right should be made.

b) There are other villages in Upper Mustang that are facing similar climate change-induced stresses as Dhye village, namely Yara and Samzung. They are also contemplating mass migration to different locations and becoming climate change refugees. Before the situation turns unbearable and the local residents decide to take drastic steps, the line agencies concerned should proactively coordinate with the villagers in devising and implementing site-specific appropriate climate change adaptation measures.

c) The capability of the local governmental agencies should be enhanced for them to identify vulnerable settlements in terms of potential climate change impacts and classify the settlements based on degree of vulnerability, install a monitoring system and regularly monitor for tell-tale signs of climate change. Small-scale pilot projects to test and demonstrate applicability of different climate change adaptation measures need to be introduced, with involvement of local residents, so that the affected settlements are convinced and ready to accept these adaptation measures.

d) Due to lack of site-specific hydrological and meteorological data of the settlements in higher mountains of Nepal, it is often difficult to link changes in different biophysical parameters with climate change. In the absence of site-specific data, researchers often rely on generated data, which may or may not match the ground reality. The DHM or other line agencies concerned should start collecting site-specific data of higher mountain settlements; the current hydro-meteorological station density in the higher mountain region is too low for reliable data analysis. For example, data collection from Lomanthang, which stopped in 1995, should be re-started.

e) Research and academic institutions should start focusing on finding appropriate climate change adaptation measures for rural communities, considering their social and cultural preferences, and economic and technological realities. Many of the recommendations on climate change adaptation measures found in national and international books, reports and journals may or may not be applicable for a particular settlement.

f) The climate change modelling capability of targeted academic and research institutes in Nepal should be enhanced. The accuracy of the results of the downscaled versions of the large-scale global circulation models for specific test sites should be tested because of the extreme ruggedness of Nepalese topography. Once this capability is enhanced, better prediction of the degree of climate change can be made and appropriate preventive steps can be taken to avoid climate change-induced disasters.

g) Since there are many settlements facing grave problems related to climate change in all ecological regions of Nepal and since it will take unacceptably long time for a few governmental or non-governmental organizations to cover all such settlements, collaborative programmes between such organizations and academic organizations should be implemented wherein the research students are supported for collecting and analysing site-specific data and information from targeted settlements so that regional approaches to climate change adaptation measures can be developed.

h) Based on extensive stakeholder consultations, standard formats, with some flexibility for site-specific conditions, for data collection related to climate change impact study should be developed for uniformity in common understanding of the various terms related to climate change. This process will assist future researchers in sharing data, information and knowledge of climate change.

i) Creation of a well-funded central website dedicated to climate change data of various locations of Nepal will reduce data duplication and prevent "reinventing the wheel" in the sense that different researchers will not have to visit the same location to collect same data repeatedly.

Future Research

Some of the research gaps noticed during the CAMUM project are listed below:

a) Mechanism to estimate depth and density of snow based on satellite images, verified by ground-based data should be developed so that simple methods like degree-day can be used to estimate water availability from snowmelt in specific areas, especially the areas adversely affected by climate change.

b) Experimental agricultural study sites should be established at targeted climate change vulnerable areas in Nepal, with involvement of local stakeholders, so that drought-resistant varieties of plants and water conservation methods developed at the study sites can automatically be transferred and easily accepted by the communities.

c) Climate change is expected to increase magnitude and frequency of floods in Nepal, partly due to increased snowmelt and high intensity rainfall of short duration. Potential downstream effects of such flood events are estimated by flood routing. Several key factors affecting flood parameters are, however, often unknown, and have to be estimated for Nepalese context, for example rugosity coefficients of Nepalese rivers. Experiment-based research to determine such parameters will be extremely helpful to all practitioners involved in climate change-induced disasters Nepal.

d) Sustainable extraction of groundwater can be an effective mitigation tool against climate change. Groundwater exploration at and targeted vulnerable settlements should be carried out so that people can have an option for fulfilling their water needs and prevent overexploitation of groundwater during droughts. This type of study should be targeted to find proper areas for groundwater recharge during rainfall or snowfall season so that groundwater can be replenished during rainfall or snowfall seasons.

Conclusion

The following conclusions were drawn based on various activities carried out as part of the CAMUM project:

a) The climate of Dhye village, Surkhang VDC-9, in Upper Mustang, and the surrounding areas is changing, as evidenced by gradual decline in precipitation, gradual increase in air temperature and gradual decrease in relative humidity.

b) The effects of climate change are getting clearer in Dhye village: the springs are drying; rainfall and snowfall seasons are shifting; precipitation is decreasing; vegetation cover is shrinking; soil temperature, vegetation dryness index and soil moisture deficit index are increasing; and normalized differential vegetation index is decreasing.

c) Drying of springs has reduced agricultural products by more than four folds and animal death has increased due to unseasonal snowfall. Decreased growth of wild herbs reduced cash income sources. After failing to cope with climate change, Dhye villagers are abandoning their ancestral village and resettling in Thangchung as climate refugees, and they have established an apple orchard at Tsawalhe near Thangchung.

d) Considering the climate change impacts on Dhye villagers, low institutional capacity to intervene in climate change adaptation measures and the de facto resettlement of Dhye to Thangchung, the best practical climate change adaptation option at this juncture is to facilitate resettlement by providing land rights, as their right as climate refugee.

e) Timely intervention and assistance to adapt to climate change are necessary to prevent more climate change refugees in Nepal.

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HIGH MOUNTAINS FACING SEVERE CLIMATIC INFLUENCE AND IMPACT ON TOURISM AND TOURISM-DEPENDENT LIVELIHOODS

Thakur Prasad Devkota[1]*, Santosh Bhandari*[1]*, Khimal Gautam*[1]*, Dil Bahadur Gurung*[1]

Executive Summary

Climate-induced disasters create severe problems in the mountain tourism sector. Various studies done at country level and worldwide have proven that Nepal is one of the worst victims of climate change, whereas it contributes only 0.025% of the greenhouse gases (GHG). The local communities of high mountain tourism destinations are the main victims of climate change. More than 90% of the respondents were aware of the impacts of climatic events and had developed adaptive capacity to combat with their adverse impacts. The majority of people in Lho and Samagaun are dependent on tourism. To study these issues, this research undertook a literature review, participatory survey method, descriptive analysis, and interviews. It also collected hydrological and meteorological data from secondary sources. The perceptions and experience from informant and community consultations coincide with authorized meteorological data, which depicts that mean annual temperature is increasing and average annual precipitation is decreasing. As an impact of climate change, the respondents observed a decrease in agricultural production, losses in biodiversity, a decrease in local resources and an increase in climatic hazards. Climate change and its associated events have an impact on expeditions, climbing, trekking in high passes, local products and cultural heritage, biodiversity, and conservation tourism. Similarly, the climate change induced disasters affect ecotourism, adventure tourism, farm base tourism, detached supply channel for destination and ultimately livelihoods of dependent people and the national economy.

The tourism-dependent communities developed their adaptive capacity to combat with the adverse effects of the climate change-induced events. They have been practicing adaptation strategies such as changes in cropping system and practices, use of local knowledge of feeding, route guide, hospitality, conservation of biodiversity, natural healing system, herbal medicinal practices, use of alternative climbing route, improved their housing system, and used local agricultural production for tourism purpose. Although they did not have enough knowledge of the mitigation measures, they were using improved stoves, protecting forests and maintaining home gardens that could reduce the rate of GHG emission.

Context and Importance

Recent discourse about the climate change is directly and indirectly related to industrial development and human civilization. The disasters and risks associated with climate change in the tourism sector are the major concerns for tourism development in Nepal. Tourism and climate change act as a two-way street, ie climate influences tourism and tourism influences climate. The first conceptual map presents a rough sketch of how tourism–climate change interactions look when broken analytically as a directional linear assessment. That change has been considered as a two-way street: climate influencing tourism and tourism influencing climate change (Patterson, Bastiononi, & Simpson, 2006). The world is moving from localization to globalization so that global concerns are also interrelated to local concerns. Climate change is also taking place globally, but the impact can be local (Puntenney, 2009). Hamilton, *et al*. (2005) argue that climate is an important factor in the destination choice of tourists and shifts international tourism flow towards higher altitude and latitude. The climatic effects on high mountains are very specific; climate change is likely to trigger the rate and intensity of natural hazards (Hamilton, David, & Richard, 2005).

[1] Sustainable Rural Development Centre, Gorkha

Various studies done at country level and worldwide have proven that Nepal, whose contribution in the GHG emission is only 0.025% (GoN, National Adaptation Program of Action, 2010), is one of the worst sufferers of climate change. About 80% of land in Nepal is covered by mountains, including lower mountains to high himalayan snow-covered areas (LRMP, 1986). Nepal's mountain region is a major tourism destination. Tourism is a vehicle for economic development, given its potential to earn foreign exchange, create employment, reduce income and employment disparities, and strengthen linkages among economic sectors, control outmigration of the local youth and alleviate poverty (Kruk, 2009), tourism is a vehicle for economic development. Climate change-induced disasters directly and indirectly impact recreational tourism and the affect indigenous knowledge system of the local cultural practices, which are linked to people's livelihoods in the alpine region (Neupane & Chhetri, 2009). Tourism plays a major role in green economy, but climate change has been severely impacting tourism resources, like biodiversity, scenic view of mountains, water-related activities and other adventure tourism activities. Nepal is rich in biodiversity, cultural diversity, geographical variations and different ecological diversities and unique landscapes, are the major attractions of the tourism in Nepal.

Several studies reported that climate change-induced disasters like landslides, floods, draughts, avalanche, heavy snowfalls, and storms are major climatic events that affect the tourism sector. High altitude and mountainous regions such as Nepal are major destinations for adventure tourism activities like trekking, mountaineering, climbing, expedition, skiing, and wildlife watching. The impact of climate associated disasters on destinations are decreasing the attraction for tourism, and impacting tourism activities. This study looked at these impacts in the context of Nepal.

Research Findings

According to the National Adaptation Programme of Action (NAPA), the observed temperature increase at an annual rate of 0.04–0.06°c and warming is more pronounced in high altitude areas compared to the Terai, ie the overall temperature increase throughout Nepal, especially in high altitude regions. Various studies show that precipitation trend also changes and extreme weather events will increase. The study shows that pre-monsoon trend will decrease and post monsoon and winter monsoon trend will increase (GoN, 2010). The Second National Communication (SNC) concluded that Nepal's increasing trend of temperature is 0.55oC per decade and the precipitation trend of most of the country is increasing 15% per decade and some part of western Nepal shows negative trend (GoN, 2014). The climatic data shows that the temperature trend is increasing and precipitation trend is decreasing near research location.

The study has provided empirical evidence about the ongoing climate change and its interrelations with policymakers, planners, stakeholders and programme implementers, donors on the overall development of the tourism sector. The study showed that most important climatic variables responsible for climatic events are temperature, precipitation and fog, as reported by the respondents. Most of the respondents were familiar with the general understanding and the remaining ones had no idea of climate change, but they understood that their local climate was changing to some extent.

The perception and experience of local people on climate change coincides with the local meteorological data, which depicts that the mean annual temperature is increasing and the average annual precipitation is decreasing. Decrease in agricultural production, loss in biodiversity, decrease in availability of natural resources and increase in climatic hazards were the impacts observed during field study. Changing trend and time of precipitation, change in altitude and month of fog, change in pattern and nature of snowfall change in rate of ice melting and change in climatic variables and associated events are having an impact on tourism resources and activities. This research summarized that, through these changes there are severe impacts on the tourism industry. The change in climatic events impact local products and cultural heritage, impact biodiversity and conservation tourism. Altogether, the climate change-induced disaster impacts ecotourism, adventure tourism, farm base tourism, detaches the supply channel for destination and ultimately affects the livelihoods of tourism-dependent people and the national economy.

The local community developed an adaptive capacity to combat adverse conditions of climate change. The local knowledge mentioned by the local respondent was very useful for adaptation practices in tourism. The findings of research from the field and literature on the knowledge system are that local tourism guide, natural and cultural healing system at high altitude, hospitality, local climbing and expedition technology, local organic agro-products, herbal product for treatment, folklore and dance, traditional nature conservation system, etc. are the major knowledge related to tourism of the local people.

Methods

Methods used in this research are descriptive and survey research design. There were altogether 113 informants interviewed for collecting information from the local people, researchers, entrepreneurs, mountain guides and tourists; and more than 100 local people participated in community consultations. The research locations are Lho and Samagaun in northern part of Mt. Manaslu in Gorkha district. The primary sources of data were field observation and survey, key informant interview and community consultations. The secondary sources of climate data were taken from the Department of Hydrology and Meteorology (DHM), which were analysed and other information and data on climate change and tourism were taken from literature. The sampling techniques used for collecting information for this research were random, cluster, purposive, self-selected and accidental sampling. Qualitative and descriptive analytical methods were used to analyse the available data. Primary data was collected from field survey, collection of perceptions of the local people; interactions with tourists, climbing and trekking guides, entrepreneurs, and trekkers at field level and researchers, stakeholders, climbing and trekking guides in Thamel, Kathmandu.

Recommendations

The issue of climate change and tourism in global discourse rose from 2003 at the first global conference on climate change and tourism, held in Tunisia. The second global conference, held in Switzerland in 2007, decided that climate change-induced events impact tourism and tourism sector also add GHG gas in the environment. So, an adaptation and mitigation strategy is required for tourism sector, but as a least developed country climate change adaptation is more important for tourism than climate change mitigation. The co-benefits from mitigation action to climate change adaptation are important for tourism of the protected areas in Nepal.

The tourism policy, strategy and planning of Nepal did not incorporate the issue of climate change. The existing Tourism Policy 2065 mention several things to developed the tourism sector in Nepal but could not include the issue of climate change which severely impact on tourism development in Nepal. The national tourism strategy has just decided in July 23, 2016 only some point of climate change mitigation included. In periodic plan of Nepal 14th plan included some issue of climate change and tourism before that any periodic plan did not address that issue. The other part the climate change policy could not incorporate tourism issue, the NAPA and other adaptation and mitigation plans/programmes/projects also had not address the issue of tourism. Now, the National Adaptation Plan (NAP) formulation process is started and the tourism, natural and cultural heritage is one of the important sectors.

Findings of this study will be helpful for policymakers, planners, by identifying the issues and areas of intervention in this sector through policy, planning and programming on adaptations, mitigation and resilience. This research gives precious information to the policymakers, planners, development workers, and researchers and even to local people by listed issues, opportunities, indigenous knowledge and practices, adopted knowledge from outside world. The finding of this study will be useful to planners to invent "Climate Resilient Tourism Development" policy that integrate the Indigenous Knowledge system, eco-friendly development intervention and local cultural practices in tourism development. It contributes to build climate resilient community and help to reduce risk of climate change-induced disasters on tourism sector and tourism dependent livelihoods. This is also helpful for local people of study area to raise their awareness on climate change-induced disasters and to build resiliency.

Considerable interest regarding the operation and empowerment of local communities while planning and implementing the tourism destinations is required. Emphasis should be given for the Promotion of Eco-tourism through use of renewable energy technology, fuel efficiency, and conservation of biodiversity with protection of environment. Execution of existing plan, policies through the coordination of all stakeholders from top to bottom of the administrative structure. Strengthen community capacity for climate resilience through, awareness raising, provision of development plan, provision of disaster risk reduction programme, etc. Make stronger information and communication system for firming the timely and effective response mechanism and plan to climate change resilient tourism infrastructure in destinations. The integration of adaptation, mitigation and resilience of the climate change into national plan, policy, strategy, programme and activities and integration of tourism into climate change policy, programme and activities are required for resilience tourism development.

Based on this research paper several recommendations have been suggested, which are summarized as follows:

- There is urgent need of Climate Resilience Tourism Development Strategies at National level for sustainable tourism development.
- Establishment of reliable hydro-meteorological station in different locations, conduct quality research and for forecasting about weather and condition of climatic variables.
- Substantial attention needs to be drawn regarding the location, operation and empowerment of local communities while planning and implementation for the tourism destinations.
- Emphasis should be given for the Promotion of Eco-tourism through use of renewable energy technology, fuel efficient devices, conservation of biodiversity, water resource and protection of environment
- Execution and review of existing plan, policies through the coordination of all stakeholders from top to bottom of the administrative as well as political structures for climate resilient tourism development.
- Formulation and implementation of low carbon development strategies in conservation and protected area tourism only.
- Reinforce community capacity for climate resilience through, awareness raising, provision of development services, provision of disaster risk reduction, and promotion of local knowledge and practices.
- Make stronger information and communication system to assure timely and effective response mechanism.
- Emphasis should be given for the provision of eco-friendly alternative tourism destination and activities focusing on adventurous and ecotourism in all geographic regions.
- Improve livelihoods of tourism dependent population through community based climate resilience tourism development strategies in mountain region.
- Strengthen the value chain of the tourism through climate change resilient infrastructure development.

Future Research

The knowledge created from this research is believed to be useful for scientific community and is expected to open the door for the further research related to climate change adaptation, mitigation and resilient tourism development in alpine region of Nepal. Further research need to conduct adaptation practices applied in tourism activities by local peoples and tourism entrepreneurs in the destination, community engagement in climate change resilience tourism development, alternative destinations, activities and alternative location for same activities, co-benefit from climate change mitigation action, climate change resilience infrastructure in destination and base camp of several high mountain, tourism friendly adaptation activities in different conservation, protected area and alpine region, impact of microclimatic variation in tourism activities. Study need to conduct climate change vulnerability, and scenario planning to build on the climate resilience tourism planning.

Conclusion

The local community developed adaptive capacity to combat adverse condition of climate change. The local knowledge mention by the local respondent is very useful for adaptation practices in tourism. The finding of the research from field and literature about the knowledge system are local tourism guide, natural and cultural healing system in high altitude, hospitality, the local climbing and expedition technology, local organic agro-products, herbal product for treatment, the folklore and dance, traditional nature conservation system etc. are major knowledge of the local peoples related to the tourism. Those knowledge affect by the adverse condition of the climate change. Integration of climate change into tourism planning, policy, strategy, programme and activities, and integrati0on of the tourism sectors into climate change policy, programme, strategy, activities for climate change resilience tourism development is required. Further research need to conduct in different sectors of tourism activities and adaptive capacity, sensitivity, and exposure of the climate change-induced events in tourism sector.

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ASSESSING THE IMPACT OF CLIMATE CHANGE-INDUCED DISPLACEMENT IN DARCHULA DISTRICT, FAR WESTERN REGION FROM A GENDER PERSPECTIVE

Sushila C. Nepali[1], Sajani Shrestha[1], Bigya Gyawali[1], Krishna Wagle[1], Log Raj Bhatta[1], Suni Shakya[1]

Executive Summary

Climate change is likely to increase the vulnerability of human communities and ecosystem as the occurrence and severity of extreme weather events, especially water-related disasters such as droughts, floods, mudslides and cyclones increase (IPCCa, 2007). Water-induced disasters are a likely effect of climate change. Climate change and water-induced disasters affect men and women differently; thus, vulnerability to this disaster-induced hazard needs to be assessed from a gender perspective. According to DFID (2008) gender-sensitive responses to climate change requires more than a set of disaggregated data, but qualitative information showing how climate change has differential impacts on women and men. It requires an understanding of the existing inequalities between women and men, and of the ways in which climate change can exacerbate these inequalities. In areas subject to periodic droughts or floods, men and women have different knowledge, management practices and exchange relationships. Vulnerability mapping is an important tool to minimize the effects of climate change and water-induced disasters. Knowing the gaps and strengthening the climate change initiative and cope with disasters, this study aims to assess the impacts of climate change and water-induced displacement from gender perspective in Darchula District, Far Western Region.

Context and Importance

Nepal is highly vulnerable to climate change. Climate change-induced disasters require special attention with policies, infrastructures and rapid responses/actions to minimize the impacts and address/adapt to the effects. The identification of the degree of sustainability of livelihoods helps in assessing the aspects of vulnerability and its magnitude for a particular community. Global climate change scenarios show that climate change is expected to increase the intensity and frequency of heat waves and floods (Coghlan, *et al*., 2014). As per Coghlan, *et al*. (2014), vulnerable groups and vulnerability vary based on groups, assets, exposure to risks and other factors. The Mahakali River Basin is an important watershed in Nepal in terms of biological and natural resources. Darchula was selected for the study due to its increased vulnerability after the major 2013 floods. Although some adaptation to current climate variability is taking place, this may be insufficient for future changes in climate. Similarly, the policy needs to pursue a sustainable development path that can reduce vulnerability to climate change by enhancing adaptive capacities and increasing resilience. Nepal has developed climate-resilient pilot project strategies having the aims to address the highest priority risks identified during the preparation process and through consultation with vulnerable communities.

Research Findings

Gender, environment and development are viewed as a sub-approach of the Gender and Development Approach, which involves gender analysis of sex-disaggregated information on experience, knowledge, and needs of male and female, specifically in regard to environment, natural resources and development. Thus, the research findings are best suited for analysis of climate

[1] Forum for Natural Resource Managers Nepal, Kathmandu

change impacts and adaptations from gender perspective as it provides sex disaggregated data on intra-community environment inputs and outputs, along with external development interventions. The findings here are based on an analysis and mapping of vulnerability, men and women's knowledge of coping and adaptation practices and government structures in place to address the issues of displacement.

Vulnerability assessment, mapping and climate change impact:

- Temperature observations in Nepal from 1977 to 1994 showed a general warming trend and increase in average annual temperature at 0.06o C (Shrestha, et al., 1999). Climate change scenarios for Nepal showed considerable convergence on continued warming, with country average mean temperature increases of 1.2°C and 3°C projected by 2050 and 2100 (Shrestha, et al., 1999). The analysis of climate change showed that the annual average maximum and minimum temperature and rainfall pattern have been changed since 2010 having an R2 =0,136, R2=.0012 and R2= .0292 respectively.
- Altogether 49% of men and 51% of women stated they did not have direct knowledge of climate change, 49% of men and 50% of women seem to have observed climate change impacts within the last thirty years.
- Both the respondents ranked flood as the topmost hazard and landslide as the second, with increase in pests and insects as the sixth event, having adverse impacts on physical, natural and economic prospects of livelihoods and making poor farmers more vulnerable.
- With unprecedented rainfall and temperature rise and fall, villages and livelihoods in Shree Bagad, Bange Bagad, Khalanga, Galfai and Dattu were found very vulnerable.
- The respondents mentioned 65-79% of the households in the area to be poor and more vulnerable compared to rich families.
- Around 29% of men and 28% of women mentioned food security becoming a problem due to hazards.
- Around 49% of men and 50% of women opined either they were never worried about having sufficient food to eat or household members spent the whole day without eating anything because there was not enough food.
- The major impacts of the climate change observed over the 10 years were seasonal change from normal to unpredictable weather, increase in hailstorms, flooding, water-logging in monsoon and droughts, mentioned by male (39-49%) and female (28-51%) respondents.
- Around 49% of male and 51% of female respondents mentioned that rainfall was not increasing during monsoon and 17% of male and 23% of female respondent mentioned that water-logging was not happening in uplands.
- Of the respondents, 31-51% of male and 23 to 51% of female observed increase in pests and use of insecticides impacting on agriculture.

Gender-based coping and adaptation knowledge

The overall adaptation and coping strategies not only rely on social construction of the people, but the practices vary based on temporal and spatial scales, which are yet to be measured in Darchula. Gender-based knowledge for coping and adaptation depends on men and women's power of freedom and decision-making.

- Male and female respondents ranked monitoring disaster risks and disaster risk reduction as the first adaptation practice along with forest and ecosystem management. The second practice adopted mentioned by the respondents was community-based disaster management for facilitating climate adaptation. Promoting community-based adaptation through integrated management was ranked third by male and female.
- The respondents mentioned village-level coping with climate change water-induced disasters as having an impact on food insecurity through improved seed varieties, vegetable farming, irrigation improvement, pest management, use of composting and horticulture practices.
- Changing crop species or using improved seeds, multi-cropping, irrigation support, off-season farming, reservoir construction for water retention and planting around the area were coping strategies not known to most of the villagers.
- With respect to water-induced disasters and climate change impacts, 49% male and 51% mentioned that there was decrease in food production, increase in invasive species, increase in flash floods and landslides and finally increase in water-borne diseases.

Structures for addressing impacts and displacement

- Temporary migration to nearby villages or to India, if they had a house there, especially during flood hazards, was observed.
- Relief and rehabilitation programmes were weakly addressed, with flood-displaced Dalit and poor households struggling to get compensation from the government.
- NAPA and LAPA initiatives are not implemented to cope with climate change effects and community lacks awareness to cope with climate change and water-induced disasters.
- Dam construction, afforestation and gabion wall construction were done by the government to minimize the risk of floods but were yet to be completed.
- The vulnerable sites need to be relocated in some proper area; however, the government does not have a provision nor the community people are willing to go anywhere because the site is a commercial hub and only linkage with India for survival for generation.

Methods

There are no studies of the climate change-induced impacts from gender perspective, which limits women and vulnerable groups from accessing services and benefit-sharing. This study tries to link the impacts of climate change with vulnerability and livelihood strategies among the displaced. For the purpose of research, a conceptual model based on climate change-related vulnerability, consequences and adaptation model was used and modified based on IPCCa, 4th Assessment Report 2007. The research design for this study was mixed with use of both qualitative and quantitative research methods. Quantitative methods were used in socioeconomic and vulnerability assessments and perception studies while qualitative methods were used for analysis of gender dimensions of vulnerability. Primary data were collected based on preliminary studies to identify the vulnerable sites, then household survey (109 households), focus group discussions among men (7 groups) and women (7 groups), field observation and key informant interviews were conducted to collect information for this study. The study area was concentrated in the most vulnerable areas based on the floods in Shree Bagad, Bange Bagad, Khalanga, Galfai, Dhap, Dattu and Uku in June 2013. Finally, data was analysed using timescales and comparative maps, photographs, as well as descriptive statistics, with help of Microsoft Excel 2010. Ladder of Life for wellbeing ranking was done to analyse the vulnerable groups of the community and the number of vulnerable households so far. Besides this, the gender perceptions and observations of hazard mapping were measured based on the ranking of the hazards and compared on a scale using Likert scale Very high to do not know in 1-5 format. The overall vulnerabilities are determined using matrices/ multi-criterion analysis and participatory ratings calculations. The Department of Hydrology and Meteorology Department temperature and rainfall data from 1988 and 1985 up to 2015 was analysed to verify it against people's perceptions.

Recommendations

In order to understand and address climate change risks, stakeholders need clear technical guidance that combines robust science with explicit consideration of user needs at local, national and international levels. This document responds to that challenge by updating and improving the existing disaster risk management plan for the future and recommends the following:

1. Vulnerability assessment and mapping needs to be done through gender disaggregated data to ensure environmental justice. For this, initial assessment of climate change vulnerability is to be conducted by analysing hydrological and meteorological data. Documenting vulnerabilities are needed for knowledge management and in future mapping to address the disaster risk issues for immediate relief and better planning.
2. Raising awareness of climate change and hazard impact and consequences is very important. The whole government, nongovernment and civil society have knowledge gap on what NAPA and LAPA do and how disaster risk management plan can effectively be implemented. Resilience capacity and disaster risk reduction plans then can be formulated to cope with climate change.
3. During the research period some key adaptation needs based on the climate change impacts were identified. Awareness training or workshops need to be conducted first to find out the real vulnerable group and vulnerable areas and what practices they prioritize as needing to be addressed. For example, in the workshops for this study, water-induced disasters were

identified as hindering food production. For this, the preferred option was to introduce new techniques for sustainable farming.

4. In the implementation of disaster risk plans, key stakeholders need to be identified and adaptation options assessed for identifying their pros and cons to achieve the desired goals. The focus here is on practical issues, such as planning, assigning responsibilities, setting up institutional frameworks and taking action.

Future Research

IPCC (2007) mentions that climate change is having an impact now and in the future on the Himalayan glaciers that sustain the base flows of many of the rivers of the Ganga Basin. This melting will increase in all global warming scenarios. Climate change has resulted in serious impacts in Nepal, especially on sectors such as agriculture and water and on those dependent on them for sustenance. There is, however, dearth of information on vulnerable communities. As a result, it is difficult to decide on the appropriate actions to be taken to reduce the adverse impacts of climate change. In fact, large numbers of adaptation programmes have failed simply because they were not able to properly identify the major aspects and magnitude of vulnerability of the community where projects were to be launched. The exact impact needs to be disaggregated across different variables and assessed continuously. Some research that still needs to be carried out is:

- Information on climate change and its consequences is still needed to address the impacts and develop policies for adaptation. In order to make people more aware, communication on climate change and modes of sharing information are to be developed.
- Analysis of the climate vulnerability and its impact based on physical and biological extents in Nepal is yet to be carried out in order to identify the key climate vulnerable areas, areas of interest to work with vulnerability and strategic entry points to address different issues such as food security, agriculture innovation, water scarcity and resilient capacities.
- Insufficient information is available there with respect to climate change and rise in diseases and vectors and, especially in Nepal, we need more research in the mid hills and low lands, which suffer from floods and landslides.

Conclusion

The overall findings focus on gender perspective and found it a very important tool to collect information in disaggregated form. Perceptions always vary between male and female based on their education, economic situation, geographical settings, livelihood opportunities and hardships of life. Most of the research works do not give gender disaggregated data and seldom give adequate information to judge the findings.

In the majority of the cases, the women respondents did not know about climate change happening, coping strategies, relief and rehabilitation programmes. Both women and men who are poor were more likely to lack knowledge, thereby increasing their vulnerability. To address this issue the challenge of gender mainstreaming has to be integrated into policymaking and implementation of projects.

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DEVELOPING A METHODOLOGY FOR ASSESSING LOSS AND DAMAGE OF CLIMATE CHANGE AND VARIABILITY IN NEPAL

Deepak Paudel[1], Ram Kumar Phuyal[1], Ramshwor Rimal[1], Hem Raj Regmi[1], Navin Kumar Lama[1], Sagar Khadka[1]

Executive Summary

The topic of loss and damage, especially non-economic loss and damage (NELD), associated with climate change is new for both science and policy. Non-economic loss and damage is classified as those "not commonly traded in markets" as opposed to economic impacts for which a market price can be attributed (UNFCCC, 2013a). In addition, losses of items and services from climate variability and extremes associated with climate change that cannot be easily assessed are termed as NELD. In current practice, reporting, accounting and assessment of NELD items and services from climate variability and extremes have not been well addressed in policy interventions in Nepal. The problem considered in the research is that because of the lack of a conceptual framework for understanding, recording, and accounting and assessing of NELDs, resilient adaptive measures are not yet addressed in climate extreme regions.

The frequency, duration and intensity of extreme events such as floods, droughts and heavy rains lead to landslides are expected to increase due to climate change. The uncertainty and risks associated with climate change are likely to exacerbate the impacts of these events. The result is increased vulnerability of human and natural systems and decreased coping and adapting capacity, which in turn poses the threat of higher levels of NELD. This will lower resilience of key systems in particular livelihood systems. With this statement, NELD items and services need to be accounted for in local-level in local-level impact assessments following climate extremes and addressed in the planning processes.

The research has found that the livelihood systems are closely linked with NELD, especially in the climate extremes-affected regions. So, reporting, accounting and assessing of NELD items and services are required to address these issues in adaptation planning from local to national levels. The economic valuation approach, including accounting values and social values, is recommended to bring the issues of NELD into policy action so that the resilience of the climate change vulnerable communities can be addressed in the future. For this, further research, in detail, projecting the possible impacts of climate extremes and variability on NELD at watershed level at different scenarios of risk is required. If we carry out such detailed research, NELD items and services will certainly be incorporated in the climate change adaptation policy in the future.

Context and Importance

Marginalized and vulnerable communities live in climate extreme regions in the lowlands and steep slopes uplands where they are more at risk of climate change impacts. These communities are vulnerable to disaster risks such as floods, landslides and droughts. While such communities practise risk reduction measures, they are not sufficient to address resilience issues of vulnerable communities. The issues of non-economic loss and damage (NELD) of items and services related with human and natural concerns are the key components for enhancing resilience. NELDs have been a particularly difficult concept since items and services are not captured in market values.

The NELD considered in the study includes loss of human life (human resources), traumatic effects, and loss of agricultural land services that have been adversely affected. These affected items and services are not yet assessed in terms of their values. Such items and services are linked to the livelihood system of the vulnerable communities. These items and services will be adversely affected if the projected figures of climate change

[1] Nature Conservation Private Limited, Kathmandu

scenario in Nepal occur. Climate change scenarios have been developed for Nepal and have been highlighted in different literature. For example, GoN (2009) reports an increase in temperature over Nepal, ranging from 0.5 to 2.0°C, with a multi-modal mean of 1.4°C by 2030, 4.7°C by the 2090s and some extremes such as increase in hot days by up to 55% by 2050, 70% by 2090, wide changes in precipitation in the monsoon (-14 to +40% by the 2030s, by increasing -52% to 135%) by the 2090s. Similarly, GoN (2008) projects that extreme weather events such as droughts, floods, landslides/debris are expected to increase in the country. In addition, NCVST (2009) shows higher increment in temperature over western and central regions as compared to eastern Nepal for the years 2030, 2060 and 2090. Under these climate scenarios in the country, NELD items and services would be even catastrophic in the future. In order to address such conditions, developing a methodological framework for understanding, recording, and accounting and assessing of NELDs, resilient adaptive measures, to some extent, can be incorporated in policy and implementation interventions.

The root causes of the research problem are concerned with different natural and human aspects. The natural aspect includes increasing uncertainty of local climate variability and extreme disasters in terms of frequency, intensity, severity and occurrence. The human aspect includes inadequacy of sensitization about NELD, lack of methods and tools for recording, accounting and assessing of NELD, non-prioritization of the issue of NELD in policy intervention, and less participation of the community, DRR and CCA stakeholders in the issue of NELD, etc.

Loss and damage issues must be incorporated from local to national level development plans and policies. Policy documents such as LAPA, local disaster risk management plans (LDRMP), and other development programmes for addressing climate change and disaster risks at local level must consider the issues, and these issues must be addressed in various future adaptation and risk reduction programmes.

Research Findings

This research found that different types of approaches, methods and tools for performing the assessment of NELD adopted by developed countries are quite challenging for developing countries like Nepal (UNFCCC, 2012; Pinninti, 2014). This is because those approaches to complex models are used with localized data, but there is a lack of localized downscaled climate variability and extremes-related data on Nepal. The research found that very limited literature addressed non-economic losses and damage (NELDs) in Nepal. Qualitative assessment, using participatory methods and tools, has been practised in developing countries to assess NELD. The study considered four NELD items and services in the research and developed a thematic framework and procedure for assessing NELDs of climate variability and extremes. The four NELD items and services include ecosystem services provisioning and regulating (soil fertility and agricultural landscape services and water sources); loss of life; loss of local knowledge and practices; and traumatic stress. The research studied the status of the four NELDs by assessing the sampled households in twelve communities (two communities in each district) living in climatic stress regions flooding (in Kailali, Mahottari and Sindhuli), landslides (in Taplejung and Lamjung) and droughts (in Dailekh). The communities have really experienced loss and damage of non-economic items and services, but they did not keep record of the losses properly. Almost all the locals in the respective districts felt that floods, landslides and droughts have caused negative impact on ecosystem services, specifically on soil fertility and agriculture products. Similarly, the locals (64% in Kailali, Mahottari and Sindhuli) responded that floods caused negative impacts on water sources. About 95% of the locals in Lamjung and Taplejung expressed that landslides caused adverse impact on their water sources. Furthermore, about 77% of the locals in Dailekh stated that less rainfall caused drying-up of water sources in the district. The economic valuation approach was tested at family level to assess the loss and damage of non-economic items and services. The flood caused loss and damage of water sources every monsoon season, and each family had contributed Rs. 2,486 (approximately US$25) to continue to access water services. Similarly, the amount contributed by the family for protection of water resources was Rs. 3,781 (US$38) and Rs. 2,523 (US$25) for protection against landslides and droughts respectively. In the same vein, each family contributed money to maintain soil fertility at the average rate of Rs. 39,233 (US$400) for floods, Rs. 36,852 (US$370) for landslides and Rs. 4,761 (US$476) for droughts. The average amount lost was Rs. 375,276 (US$3,750) for damage of agricultural production, Rs. 905,743 (US$9,057) for landslides and Rs. 73,872 (US$7,387) for droughts. The research assessed the loss of local knowledge and practices and traumatic losses due to climate stress at family level in terms of social values. The effects of climate stress on loss of local knowledge and practices and traumatic loss were combined and the result showed that the negative impact due to flood was 74.73%, due to landslide, 53.34%, and due to drought, 67.74%.

Developing a methodology for assessing the loss of life from climate extremes was difficult. The research reviewed the existing practices being addressed and the issue of loss of life from climate extremes. Humanitarian relief and insurance approaches are being practised to address the issue of loss of life. For example, the Government of Nepal provides Rs. 40,000 (US$400) per person to the family of the deceased for performing her/his last rites (MoHA 2064). The government also provides an amount up to Rs. 100,000 (US$1,000) to the family of the deceased as immediate relief. Likewise, in the case of road accidents, the insurance company pays approximately Rs. 500,000 (US$5,000) per person to accident victims. In the case of loss of life in natural disasters, the life insurance policy pays to the families of the insured in case of her/his death due to natural or man-made disasters, but this is not widely practised in Nepal. In addition, the research employed an approach for thematic discussion of this issue. In this approach, the research interpreted the lifecycle hypothesis (LCH) (Modigliani and Brumberg) in terms of expenditure and income throughout life. If a person loses his/her life due to natural disasters, he/she will lose his/her economic value in terms of accounting value (quantifying) and social value (qualifying). The lifecycle age from 18 years (the age when one formally starts income generation in the country) to 68 years (national life expectancy) is considered in understanding this theory for performing the value of loss of life. In general, 28 to 58 years of age is the income-generating age in a person's life, and 35 to 50 years of age is the period of rising income in life in general. This concept was interpreted in two communities in flood-affected regions in Kailali. For example, the increased earnings period is the age range 28-38 years and the earning slightly falls in the age range 38-48 years and again slowly increases up to the age of 68 years. This shows that marginalized people live in flood high risk region and the income-generating period throughout the life differs by age groups. Furthermore, if a person dies at a young age (say at 30 years) in a natural disaster, he/she will lose his/her income during the rest of the life till (say up to life expectancy age). The lost income amount can be considered equivalent to loss of life in quantifying. The social value, including dignity, performance in society, acceptance level of the risks at different level, will be lost if a person dies in a natural disaster. The research found that a further detailed discussion is required to adopt this approach in policy interventions in the future.

Methods

The main purpose of the research was to explore the losses and damage caused by climate variability and extremes in general and explore the methodologies to recoding, accounting and assessing non-economic losses and damage due to rapid and slow climate extremes in particular. The research adopted literature review to understand the concepts, types and nature of NELDs and to explore the methodological framework for recording, accounting and assessing NELDs. Qualitative and quantitative approaches were employed in the research. The qualitative approach has been an usual practice in developing countries for assessing loss and damage of climatic extremes. In quantitative approach, substitution and replacement and contingent valuation method were performed in the assessment of NELDs, particularly for quantifying the loss of services of soil and water. These approaches were employed at household level in the selected communities in six districts. Likewise, the lifecycle hypothesis (LCH) approach was employed to assess loss of life due to climatic stress. This approach was also tested in the case of flooding. The performed methodologies were interacted in three ecological regions (Kailali in Terai for floods, Dailekh in Hills and Taplejung in Mountains for droughts). The evidence-based losses and damage were recorded by using participatory approaches such as focus group discussion (FGD), key informant interview (KIIs), transect walk and direct observations. The district-level interactions covering three ecological zones and three types of climate extremes (floods, landslides and droughts) were carried out for sensitization of the issues and validation of the approaches with district-level planners and implementers. Experts and professionals at individual and agency level were met to explore the issues and possible procedures for assessing the loss of life and other NELD services.

Recommendations

Loss and damage is considered as an emerging dynamic system in which there is interaction of climate change with social processes, which transforms human societies. The projection of climate showed that there is an increase in temperature with irregular pattern of rainfall, which is the cause of various climate-related disasters. This is a new issue for understanding and assessing NELDs for developing countries like Nepal. The sensitization about NELDs is important in all sectors of planning and implementation from community to national level. In addition, loss and damage issues should be incorporated sector wise. Recording, quantifying and qualifying NELDs sector-wise helps to distinguish the sector more vulnerable to climate extremes and variability, which will enhance the existing coping and adaptation strategies. Loss and damage issues should be included into various governmental documents and formats. In addition, farmers need to themselves assess the loss and damage of their own land. If farmers start to record the cost and benefit of getting services from land, they can easily assess the loss and damage of direct and indirect services of the land. At local level, the capacity of agricultural centres to assess the loss of services and indirect goods should be built. For the assessment, farmer users committees need to be developed and the committee could do the valuation of the services that are lost in natural disasters. After accounting for and recording such items, further assessment and valuation of such materials will be easier and the data can be crosschecked at local level. The existing format of recording disaster impacts needs to be modified to make a standard format and guideline for loss and damage recording and assessment at local and national level. Regular monitoring and evaluation of data collected on loss and damage should be maintained. Finally, detailed further discussion from policy to implementation levels is required to identify the methodologies for assessing NELDs of climate change to address the issues in future policy interventions.

Future Research

As discussed above, the issue of L&Ds, including ELDs and NELDs, is newly emerging in developing countries. Several further discussions and research are required to address the issues for integrating disaster risk reduction and climate change adaptation in development interventions. In addition, it is important to convince the policy-decision makers to formulate policies in favour of the farmers and the locals to get additional support and resilient measures in the future.

The key points for future research are listed below:

- Detailed methodology for the valuation of loss of life;
- Linkage of post-traumatic stress in livelihood assessment;
- Downscaling of climate change forecasts and developing a scenario of impacts, especially L&Ds; the research should focus on: why is rainfall variability becoming severe?; does its cause go to having less water in monsoon or any other causes of droughts? For example, why are wells in rural regions drying up?
- Identification of climate suitable crop species and what are their losses due to climate change.
- Forecasting of future scenario at local level.

Conclusion

NELD has been an emerging subject for researchers. Only direct items and materials of loss and damage have been valued into market price till date. Now, researchers have to divert their interest to indirect items and services as they have equal contribution in changing the economic costs of the nation. So, L&Ds, especially NELD issues, should be recorded and accounted for to estimate the real loss and damage. Climate extremes are directly or indirectly linked to livelihood. In order to reduce loss and damage issues, both national and local levels should participate in risk and vulnerability assessment. Standard guidelines or format should be formulated to incorporate NELD issues in every sector, as well as in various developmental and adaptation programmes and policies.

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Public Health

STUDY AND ASSESSMENT OF ENVIRONMENTAL BURDEN OF DISEASES ATTRIBUTABLE TO CLIMATE CHANGE IN NEPAL

Srijan Lal Shrestha[1], Iswori Lal Shrestha[2], Niraj Shrestha[3]

Executive Summary

The study is conducted with the objective of quantifying and assessing the environmental burden of disease (EBD), which can be attributed to climate change in Nepal. Climate change projections for Nepal show evidence of increasing average surface temperature and changes in nature, intensity and frequency of precipitation. These marked changes in climatic conditions are bound to affect the people of Nepal, specifically their public health concerns. The study analyses the trends in mortality and morbidities related to climate-sensitive diseases like water-borne, vector-borne, urinary system and heart diseases, compared to changes in climatic variables. It contributes to understanding the extent of the effects of climate change on public health concerns. Results of the study showed statistically significant correlations between climatic variables and disease incidence assessed by hospital in-patient morbidities and mortality and a rise in surface air temperature. It also showed a significant correlation between the rise in deaths and heart disease morbidity and extreme hot and cold temperatures. Study findings demonstrated that substantial proportions of disease attributions can be linked to a rise in air temperature. These trends show that Nepal's population and authorities need to face the challenge of rising disese incidence as one of the impacts of climate change and improve public health preparedness and adaptation strategies. Potential adaptation strategies include promoting cleaner environmental conditions and better hygiene practices, improved prevention and early treatment of diseases in terms of both services and improvement of infrastructure and facilities. Key strategies also include assessing and educating vulnerable populations and enforcing regulations and laws to protect public health and the environment as far as possible and feasible.

Context and Importance

According to literature review, quantification of health effects accounted by hospital mortality and morbidity that can be attributed to climate-related variables based upon local daily time series data in Nepal was non-existent. The lack of known health effect coefficients related to various climate-sensitive diseases like water-borne and vector-borne diseases has resulted in lack of knowledge of the extent of effects that can be attributed to major environmental risk factors like temperature and climate change in Nepal. Such estimations, if available, can help policymakers and planners to develop future mitigation and adaptation strategies for the benefit and welfare of the people and formulation of policies and climate-resilient development programmes. Adaptation is concerned mainly about warning people in advance about the catastrophic events that can occur and preparing them to deal with vulnerability and uncertainty.

Research Findings

Results of statistical modelling with distributed lag effects (current and previous day's effects) showed that rise in atmospheric temperature is statistically associated with rise in hospitalization due to water- and vector-borne diseases and deaths associated with these diseases, as well as hospitalization of urinary system diseases with 3-10% rise in hospitalization/deaths per 1°c rise in average temperature. Furthermore, all deaths, and hospitalization due to heart disease (HD) increased with increasing hotness or coldness relative to overall average condition (20°c), implying that extreme conditions could increase death rate and

[1] Central Department of Statistics, Tribhuvan University, Kirtipur
[2] Nepal Environmental and Scientific Services, Kathmandu
[3] Nepal Medical College, Kathmandu

HD hospitalization compared to normal condition. It was calculated that with 1°c rise in absolute difference of average temperature compared to 20°c, there was 1.4% rise in all cause mortality and 2.5% rise in HD hospitalization.

Effects of rainfall are detected with 2.2% rise in WB hospitalization per 1mm rise in rainfall and 0.7% to 4% decrease in vector-borne and urinary system hospitalization per 1mm increase in rainfall. Relative humidity is found associated with -1.5%, 4.1%, 0.6% and 0.5% change in water-borne, vector-borne, urinary system hospitalization and all cause mortality per 1% rise in relative humidity respectively. Wind speed is found to be associated with 2.1% to 5.2% increase in the WB, VB and HD hospitalization/deaths per 1 m/s rise in wind speed and negatively associated with 4.1% and 12.8% decrease in urinary system disease hospitalization and deaths per 1m/s rise in wind speed respectively.

Health effect estimates are also computed separately for different eco-belts and age groups, with focus on children and elderly population. Results showed varied effects in the direction, as well as extent of effects between eco-belts and age groups, which may be due to various differences between the eco-belts of Nepal and age-specific adaptability, vulnerability and susceptibility of people. Attributable fractions (AFs) are needed to assess the proportion of disease burdens that can be linked to climatic conditions. Analysis showed AFs between 0.1 and 0.67 for hospitalizations with highest AF computed for VB diseases and lowest for HD. AFs for WB diseases and urinary system-related diseases are computed as 0.38 and 0.29 respectively. Considering hospital mortalities, AFs for all cause mortality and disease-specific mortality (WB and VB) are found to be 0.06 and 0.43 respectively.

The attributable burdens, ie the frequency of people whose effects can be said to occur due to climate-related variables, are found very high in case of WB diseases, with around six hundred thousand cases attributed to temperature in Nepal annually. Similarly, attributable burdens are found to be around fifty thousand cases of VB and urinary system diseases and twelve thousand cases of HD, which can be attributed to temperature annually. Similarly, among deaths, around 160 of all cause deaths and around 65 of WB and VB disease deaths can be attributed to temperature annually.

For estimating the effects of climate change, two scenarios are considered, the baseline scenario (1985-2014) and the future scenario (2015-2045). Attributable burdens (ABs) are computed for both scenarios, taking into account only climate change, while assuming total burdens and other factors like development level, socioeconomic conditions, population, etc. remain unchanged in the two scenarios. The percentage rise in ABs in future scenario is found to be higher for urinary system (7.2%), VB (4.6%) and WB (4.32%) among hospitalizations and WB and VB disease deaths (7.02%). In contrast, attributable burdens decrease for HD hospitalization and all cause mortality with 2.22% and 1.52% decrease in ABs in climate change scenario respectively.

Methods

A total of ten districts are covered in the study: one from Mountain (Dolakha), five from Hill (Kathmandu, Lalitpur, Bhaktapur, Kavrepalanchowk and Dhankuta) and four from Terai (Chitwan, Sunsari, Morang and Jhapa), which cover 23.8% of the total population of Nepal according to the 2011 Population Census. Meteorological data is collected for weather variables, namely temperature, rainfall, humidity and wind speed for 2009–2014 period from 16 stations located within the districts covered by the study, which included two from Mountains, eight from Hills and remaining six from Terai, and collected from the Department of Hydrology and Meteorology (DHM), Kathmandu. Disease burden data assessed by inpatients and deaths are collected on daily basis from hospital records of the leading hospitals in the study areas, including government, teaching and some private hospitals, for the reference period of five years from 2066 BS (April 2009) to 2070 BS (May 2014).

Altogether 22 hospitals are referred from the selected districts, which included two from the Mountains, thirteen from the Hills and seven from the Terai. Data are collected for WB (enteric fever, diarrhoeal diseases and hepatitis), VB (malaria, dengue, encephalitis, leishmaniasis and filarisis) diseases, heart diseases (ischemic heart disease, angina pectoris, cardiovascular arrest, cardiac failures, etc) and urinary system diseases (chronic kidney diseases, urinary tract infections, renal failure, etc) and also all cause mortality and disease-specific mortality of the above-specified diseases. In-patient records showed around 50,000 hospitalizations of the diseases concerned and around 10,000 all cause deaths and 435 WB and VB disease deaths. Data on the total disease burden is collected for seventeen years from the annual reports of the Department of Health Services (DoHS).

The confounding variables included to account seasonal effects, holiday effects and trend component. Several descriptive analyses are performed. Estimates with relative risks are obtained from exposure-response modelling to measure the overall, eco-belt-specific and age group-specific effects. Estimation of EBD is carried out with computations of AFs and ABs that can be attributed to temperature as the main climatic variable and then climate change in Nepal, comparing baseline and future periods based upon methodology developed by the World Health Organization (WHO). Temperature data for baseline period is obtained as the gridded atmospheric reanalysis data provided by the National Centre of Environmental Protection (NCEP) and National Centre for Atmospheric Research (NCAR). Future scenario of temperature is approximated using Regional Climate Model (RegCM3) for Nepal with 0.25°c increase in average temperature per decade.

Recommendations

Scientific community has accepted that the main cause of global warming is increased GHG concentration in the atmosphere due to emission from vehicles and factories, overuse of fossil fuel, deforestation, changes in land use pattern, etc. Thus, in order to address the important issue of global warming and, in the context of Nepal, there is need for widespread use of renewable energy and fuel-efficient products and systems in different sectors, including domestic and transportation; switching of transportation modes from petroleum product-driven vehicles to electric vehicles and modern railway system in possible areas; improvement in agricultural practices/techniques using appropriate manure/fertilizers to increase soil carbon storage; improvement in forest and waste management systems; ecology-friendly urbanization so that 'concrete jungles' with water scarcity are not created. This includes ensuring availability of grasslands and plantation of trees in cities that recharge groundwater, which would prevent extremes of temperature and protect from droughts; cooperation between underdeveloped and vulnerable countries like Nepal with developed and other countries responsible for emission of maximum GHG.

The present study has found that increase in average temperature increased the risk of water-borne, vector-borne and urinary system-related diseases. Substantial proportion of WB diseases can be reduced by improving sanitation and focusing on personal hygiene. For prevention of VB diseases, personal protective measures such as use of mosquito nets, mosquito repellents and insecticides should be encouraged. Regular actions should be implemented to control breeding grounds for mosquito like drainage of stagnant water pools where mosquitoes breed. Effective Information Education Communication (IEC) programmes need to be carried out to raise awareness of various health-related aspects due to climate change with adequate coverage in both rural and urban areas. Regular disease surveillance by national healthcare delivery system is also important for preventing disease outbreaks. Special attention should be given to more vulnerable sections of society such as children and the elderly, poor and underprivileged communities. Governmental and non-governmental organizations should encourage climate-resilient investments.

The present study showed some significantly varied health effects between the eco-belts of Nepal and vulnerable age groups (children and elderly), which indicate that preparedness and adaptation strategies should be implemented as per the need of specific regions and specific age groups. For instance, the effects of temperature rise on WB disease hospitalization are found to be two times higher in the Hills and Mountains compared to the Terai, which suggests identification of region-specific preventive measures, plans and policies and their implementation. The Government should explore ways of improving supply and storage of drinking water, as well as preventing mixing up of toxic sewage in rivers, particularly in the Hills and in summer and rainy seasons.

Heart disease hospitalization is also found higher in the Hills compared to the Terai; so people residing in those regions should be made aware of preventive measures against HD. In contrast, the effects of temperature rise on VB disease hospitalization are found higher in the Terai compared to the Hills, suggesting relatively more attention required in the Terai in this respect supported by disease control, surveillance, preventive measures, etc. Furthermore, VB disease hospitalization is found consistently associated with high temperature, low rainfall, and humid and windy days in the Hills as well as in the Terai regions, which calls for more care in such conditions. In the Hills, the effects of rainfall on WB and urinary system disease hospitalization are found to be positive, whereas negative in the Mountains and/or the Terai. This suggests that, in the rainy season, water sources/supplies could be more contaminated in the Hills and, therefore, more preparedness is required in the region against spread of WB and urinary system diseases. Children are found more prone to WB diseases at the time of seasonal changes. They are also at higher risk of mortality due to extreme temperature conditions and heavy rainfall. Hence, preventive measures should be taken to protect them from these risky situations.

Similarly, elderly people are found relatively more vulnerable to mortality due to extreme atmospheric conditions like very hot and cold days, which calls for extra precautions/protections in such conditions. Further studies are required to assess the effects of climatic variables on disease burden in Nepal to obtain more representative estimates and also since varied effects are detected between eco-belts and relationships are complex. Lack of proper and standardized hospital database system is a major obstacle for conducting research related to disease burden in Nepal. It is high time a mechanism was established for an integrated database system covering all health institutions of Nepal so that studies could be conducted more effectively and made available for researchers through standardized regulations/approval system.

Conclusion

Health effects assessed by hospital in-patient morbidity and mortality related to water-borne and vector-borne diseases, heart and urinary system diseases as well as all cause mortality are statistically and significantly associated with climatic variables and confounders like seasonality, day of week effect and trend. Results showed substantial increase in WB, VB and urinary system-related hospitalization with increase in average surface temperature and other effects like heart disease hospitalization and even deaths due to extreme weather conditions, with varied extent of effects between eco-belts and age groups. Thus, this warrants for more effective plans and policies particularly related to adaptation, preparedness and preventive measures to combat against the odds of changing climatic conditions in the long run to address the public health concerns of Nepalese people.

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IMPACT OF CLIMATE CHANGE ON CHOLERA OUTBREAK IN NEPAL

Supriya Sharma[1], Geeta Shakya[2], Megharaj Banjara[1], Anjana Singh[1]

Executive Summary

Traditionally, cholera has been viewed as a strictly faecal-oral infection but recently increased attention is being paid to the environmental determinants of the disease. Therefore, this study was conducted to assess the impact of climatic factors – temperature (maximum and minimum), rainfall and relative humidity on the disease, cholera and its causative agent, *Vibrio cholerae*. For this, a prospective longitudinal study from March 2015 to April 2016 was done by isolating *Vibrio cholerae* on monthly basis from the surface water of Kathmandu, Lalitpur, Bhaktapur and Kavre as hilly districts and Chitwan as a Terai district. Similarly, socio-demographic factors associated with cholera outbreak were also analysed by conducting focus group discussion among the residents of cholera outbreak area. Moreover, a retrospective study was conducted by doing time series analysis of monthly number of cholera cases in Kathmandu from 2008 to 2014 and climatic factors for the same period. The climatic factors did not show any association with the number of cholera cases. Rainfall, relative humidity and minimum temperature were, however, positively correlated with the isolation of *Vibrio cholerae* from water samples. The persistence of *V. cholerae* in the environment of Kathmandu and poor quality of drinking water and scarcity of safe water signify that there is a risk of occurrence of cholera outbreak in Kathmandu Valley, if suitable climatic conditions occur. Therefore, strategies for early detection of cholera cases and proper interventions should be developed and employed at local and national levels.

Context and Importance

Climate change is a significant and emerging threat to public health. WHO has identified cholera and other diarrhoeal diseases as one of the major health consequences of climate change. Water-borne diseases emerge after excessive or scarcity of water (Dhimal & Bhusal, 2009). Both scarcity of water, which is essential for hygiene, and excess water due to more frequent and torrential rainfall will increase the burden of diarrhoeal disease, which is spread through contaminated water. Globally, there are an estimated 3-5 million cholera cases and 100,000-120,000 deaths due to cholera each year. Several studies have shown the occurrence of cholera in Nepal (Anniss, 1966; Gimlette, 1886; Pokhrel & Kubo, 1996; Shakya, *et al*., 2012; Sharma, 2006; Shrestha, *et al*., 2010; Tamang, *et al*., 2005; Yamamoto, *et al*., 1995) and 26 districts have been categorized by the Epidemiology and Disease Control Division as high risk outbreak prone districts, expecting one to three diarrhoeal disease outbreaks per year (DOHS, 2011). Along with such burden, diarrhoea is also highly linked with frequency and intensity of occurrence of extreme climate events such as droughts and floods, being responsible for such water-borne disease occurrence (Bhandari, *et al*., 2012; Dhimal & Bhusal, 2009; Joshi, *et al*., 2011). The survival of Vibrio cholera, the causative agent of cholera, in aquatic environments is linked to both abiotic and biotic ecological factors, which are likely to be influenced by climate change. Yet, little attention has been paid to the possible impacts of these predicted climate changes on water-borne diseases such as cholera. Therefore, this study aims to investigate the association of various climate factors with the occurrence of cholera and its causative agent–*Vibrio cholerae*.

[1] Central Department of Microbiology, Tribhuvan University
[2] National Public Health Laboratory,

Research Findings

Vibrio cholerae persists in the environment (river sediments) throughout the year except in December and January, and only during monsoon in surface water of Kathmandu. Rainfall and minimum temperature were positively associated with the isolation of *Vibrio cholerae* from both water and sediment samples.

The disease cholera seems to be endemic in Kathmandu and cases appear throughout the year with seasonal rise in cholera cases starting from July. Temperature (maximum and minimum), rainfall and average relative humidity did not show any positive correlations with the number of cholera cases.

The socio-demographic characteristics showed poor sanitary conditions and the use of untreated drinking water by the residents of the community where cholera outbreak occurred.

Methods

This study was conducted from March 2015 to Aug 2016 after obtaining ethical approval from Nepal Health Research Council, Kathmandu. During the initial phase of the project, communication was done with different organizations, viz Central Department of Microbiology, Tribhuvan University, Epidemiology & Disease Control Division and Sukraraj Tropical & Infectious Diseases Hospital (STIDH), for the execution of the project. A prospective longitudinal study (March 2015 to February 2016) was conducted with water and sediment sample collection for isolation of *Vibrio cholerae* on monthly basis from different sites of Kathmandu, Lalitpur, Bhaktapur and Kavre as hilly districts and Chitwan as Terai district. The association of climatic factors with *Vibrio cholerae* isolation was analysed by using statistical tools. Similarly, confirmed cholera cases were tracked from STIDH and FGDs conducted among residents of cholera outbreak areas. Similarly, a retrospective study was conducted by doing time series analysis of monthly number of cholera cases in Kathmandu from 2008 to 2014 and climatic factors—temperature (maximum and minimum), relative humidity and rainfall for the same period.

Recommendations

- The government should ensure safe water supply, at least for drinking purpose in an amount enough to meet the demand of the community.
- The government should initiate awareness programme by focusing on the preventive measures of cholera at the community level.
- Capacity building should be done at local level for early detection of confirmed cholera cases in the laboratory.

Conclusion

The climatic factors did not show any association with the number of cholera cases in Kathmandu. Rainfall, relative humidity and minimum temperature were, however, positively correlated with the isolation of *Vibrio cholerae*—the causative agent of cholera from surface water samples. The persistence of *V. cholerae* in the environment of Kathmandu and poor quality of drinking water and scarcity of safe water signify that there is a risk of occurrence of cholera outbreak in Kathmandu Valley, if suitable climatic conditions occur. Therefore, strategies for early detection of cholera cases and proper interventions should be developed and employed at local and national level.

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IMPACT OF CLIMATE CHANGE ON DENGUE VIRUS INFECTION AMONG HUMAN AND AEDES VECTOR

Reshma Tuladhar[1], Megharaj Banjara[1], Ishan Gautam[2], Anjana Singh[1]

Executive Summary

The virus transmitted to humans by the bite of infected Aedes mosquito causes dengue. This mosquito vector acquires the virus when it feeds on infected humans. Dengue has become a public health concern since it is spreading around the world, mostly in tropical and sub-tropical regions. More than 2.5 billion people are living in regions endemic to dengue. The first outbreak of dengue in Nepal occurred in 2006, followed by massive outbreaks in 2010 and 2013. Each year numerous dengue cases are reported primarily from Parsa, Chitwan, Rupandehi, Nawalparasi and Jhapa in the Terai. Cases have, however, been detected from Tanahun, Lamjung and hilly areas of Chitwan, which are considered free from dengue vector. Climate change is one of the factors considered to be contributing to the spread of this disease across the country.

Context and Importance

Climate change is posing a threat to human health with the emerging risk of increased incidence of vector-borne diseases. In 2003, only eight countries in South East Asia Region reported dengue cases, which increased to eleven countries in 2006. Dengue was previously confined to the Terai region, but later it was detected in-patient in Kathmandu who has no history of travel to dengue-affected areas.

Multiple factors such as rapid and unmanaged urbanization in developing countries, globalization of trade, increased travel and global warming are considered as the contributory factors for the global expansion of dengue. Increase in global temperature, precipitation and relative humidity are likely to increase the transmission season of vector-borne disease and expand their geographic range. This can make the regions that lack either population immunity or strong public health infrastructure most vulnerable to this disease (IPCC 2007).

The trend of increasing temperature in higher altitudes and reports of dengue cases from hilly regions necessitate investigating the vector density and cases of dengue. Presence of vector indicates the potential emergence of dengue cases in the hilly regions of Nepal. This work was designed to determine the relationship between dengue cases with trend of climate factors and determine vector prevalence.

Research Findings

- **Vector breeding:** The mosquito vector for dengue preferably breeds in discarded tires. Other discarded containers with potential for water collection are plastic containers, plastic drum, plastic cups, glass, metal drum, metal container, metal can, etc. The dengue vector prefers clean water for breeding; so, they were not found in dirty and stagnant water.
- **Vector abundance season:** The population of vector is high during monsoon season. High rainfall of the year falls during July, August and September months. This allows water to get collected in potential containers, thus, making it favourable for mosquitoes to breed. Besides, the temperature gets warmer during this season, making the environment suitable for mosquito vector to breed. The number of vectors is low during post-monsoon and pre-monsoon due to lower temperature and relatively dry environment with scarce water containing container. The eggs of the dengue vector can survive drought and low temperature.

[1] Central Department of Microbiology, Tribhuvan University
[2] Natural History Museum, Kathmandu

Dengue cases were found to increase when the minimum temperature and relative humidity increase. Minimum temperature is the record of lowest temperature of the day and it is critical to mosquito survival and breeding compared to maximum temperature. Similarly, increase in relative humidity also facilitates the breeding of mosquito. Increase in mosquito population is likely to increase the possibility of spread of disease.

Methods

The vector density and the possible breeding habitats in Kathmandu, Lalitpur and Chitwan were investigated by vector surveillance. During vector surveillance, house premise were searched for water-containing containers. Since such containers are possible breeding habitat for vector, the larvae of vector were searched and collected. Larvae were reared in a laboratory to emerge into adults, which were identified and recorded. Similarly, the monthly dengue cases for the past six years were compared with monthly recording of temperature, rainfall and relative humidity, using statistical analysis tools.

Recommendations

The results of this research show that vector of dengue is present in different locations of urban area of Kathmandu, Lalitpur and Chitwan, which were abundant in monsoon. Most of the dengue cases in the country were recorded from Chitwan. Frequent travel of people within Chitwan and Kathmandu Valley and presence of vector in Kathmandu and Lalitpur are warning signals that dengue incidence can increase in these areas if timely action is not taken for their containment. Taking even a simple step towards controlling vector will contribute to the vector control and the strategies for vector controls are:

1. **Improve drinking water supply:** Poor drinking water supply in cities compel people to store water or harvest rainwater. If stored containers are left open, it will be a suitable breeding habitat for vector. Water supplied to cities is stored before distribution. Such reservoir should be properly managed to prevent breeding of mosquitoes.
2. **Proper disposal method and cleanliness:** Effective disposal of waste will prevent open exposure of waste materials. Plastic cups, metal cans, tin, glass and waste materials in the garbage can hold rainwater during monsoon. Such water-containing containers can be perfect breeding places for vector. Thus, the general public should not litter in open space and the municipality should collect and manage garbage effectively.
3. **Not allowing water to retain in tires:** Most of the breeding habitats were discarded tires. Thus, heaps and piles of tire should not be kept in open spaces. Even if they have to be, it will be wise to bore holes in each tire so that water will not retain in it.
4. **Proper management of potential breeding containers:** Since artificial containers are breeding habitats in urban areas, any water-holding container, when not in use, should be turned upside down. This will prevent water retention during rainy season.
5. **Campaign for awareness and hygienic living:** Dengue awareness to public should be done via media to alert people from potential outbreak. Maintaining cleanliness in the city should be the priority.

Future research

Intensive vector surveillance is necessary to be carried out each year. Statistical approach to model dengue transmission and persistence of vector will be informative.

Conclusion

It is not possible for human to stop the climate change. It is, however, feasible to adapt to the impact of climate change. Hence, if timely efforts are taken to control the vector-borne disease that is likely to increase with climate change, the consequence we will face in the future will not be dreadful.

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Urban Settlement and Infrastructure

SUSTAINABLE URBAN TRANSPORT SOLUTIONS TO MITIGATE CLIMATE CHANGE: A CASE STUDY OF KATHMANDU VALLEY, NEPAL

Ashim Ratna Bajracharya[1], Shanti Bajracharya[1], Mahendra Ratna Bajracharya[1], M.S. Pradhan[1], Sunil Dhungana[1]

Executive Summary

Sustainable transport systems are those that aim to reduce emissions, fossil fuel consumption and the consumption of natural land. Most fundamentally, more emphasis should be on reducing the role of private vehicles as the prime mode of transport and shifting travel towards other sustainable modes such as public transit, cycling and walking.

The cities of the Kathmandu Valley are in the stage of rapid urbanization and are experiencing the many problems that emerge with such growth. There has been a sharp increase in all forms of transportation usage, and more vehicles on the road to meet the demand of a growing population and high level of economic activities. This has resulted in a situation of unsustainable mobility, which has caused severe negative impact on urban climate due to excessive vehicular emissions.

In this research, to estimate emissions, an urban transport model was used to predict a travel pattern for the city. The result for the base scenario shows that annual CO_2e emission is about 200,000 tons annually, which is approximately 20% of the total valley emissions. As a mitigation measure to reduce emission, introduction of efficient public transport system in the form of Bus Rapid Transit System (BRTS) along major corridors could bring down emission by about 10% in overall emission from urban transport sector, as per the current potential shift of 25% from private vehicle users.

The urban transport sector is one of the major sectors responsible for urban climate change and the temperature of the valley is in the rising trend due to excessive accumulation of GHG. From scenario analysis, it was clearly seen that the more people used public transportation, rather than private vehicles, the more GHG emissions could be reduced.

So, promotion of public transport should be given topmost priority in city development strategies and also at policy level so that more of such systems could be brought in operation.

Context and Importance

Mitigation, in the context of urban transport, implies reduction in greenhouse gas emissions, resulting from the movement of goods, services and people in cities.

Urban transport is one of the major sectors for energy consumption and GHG emission. As the level of GHG increases, it will have severe impact on urban climate. So, it is very crucial to promote sustainable transport development strategies in order to minimize the climate change impacts, resulting from the transport sector.

Kathmandu Valley comprises three districts, Kathmandu, the capital city, Lalitpur and Bhaktapur, with population of over 2.5 million (CBS, 2011). All these three regions are facing rapid urbanization as migration from the outskirts continues at a rapid rate. With population growth, the city sprawl is increasing without adequate infrastructure and planning measures. This is causing degradation in city landscape and inefficient mobility.

In terms of mobility, the narrow roads, increasing use of private vehicles (motorcycles and cars), low occupancy public vehicles (micro bus and tempos) and insignificant use of non-motorized modes (bicycles) are responsible for inefficient urban mobility (Table 1 and Table 2). As a result, the roads are all the time congested, resulting in delays due to increased travel time, along with air pollution due to excessive emissions.

[1] Department of Architecture and Urban Planning, Institute of Engineering, Tribhuvan University

Table 1: Vehicle Registration data for Bagmati Zone (1989/90 - 2013/14)

Year	Bus	Mini Bus	Car/Jeep/Van	Micro Bus	Tempo	Motorcycle	Others	Total
1989/90	797	1,028	9,868	-	507	18,594	3,812	34,606
2013/14	8,298	7,023	93,847	1,720	2,518	601,951	40,189	755,546
Total	**9,095**	**8,051**	**103,715**	**1,720**	**3,025**	**620,545**	**44,001**	**790,152**

Source: (DoTM, 2014)

Table 2: Overall Modal Split for Daily Trips (Work and Education)

Mode	No. of Trips	Percent
Bicycle	20	0.4
Bus	1487	28.6
Car	603	11.6
MC	1897	36.5
Tempo	86	1.7
Walking	1098	21.2
	5191	

Source: Household Survey

Research Findings

GHG emission is one of the major causes of climate change. Urban transport system of Kathmandu Valley is responsible for significant amount of emission, which has major impact on air quality in the valley, and contributes to global GHG emissions. For estimating emissions, traffic volume was estimated using the Urban Transport Model. The results show an estimated CO2 emission from urban transportation of 197,150.3 tons. This emission figure is about 20% of the total Kathmandu Valley emissions. The total valley emission is estimated from the fuel consumption data, which is obtained by the share of the Kathmandu valley out of the national sales. Vehicular emissions are contributing

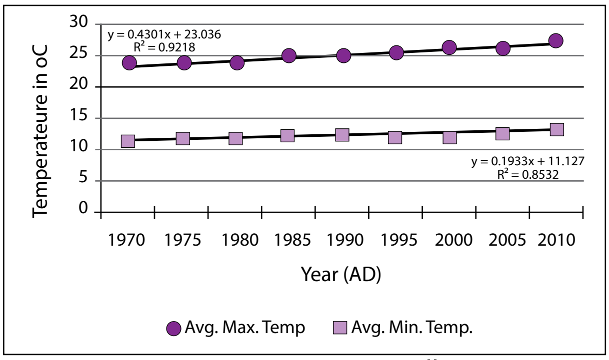


Figure 1: Rising Temperature in KTM Valley (Source: (DHM), Station: KTM Airport

significantly to GHG emission. This will have profound effects on air quality in the Kathmandu Valley and is a significant source of Nepal's GHG emissions. We see gradual increase in the rise of temperature due to excessive accumulation of GHG in the atmosphere of the valley. It is seen in temperature trend line that was analysed over the course of the last four decades (Figure 1).

Role of mass transit in reducing emissions:

Public transportation can help reduce emissions significantly if more commuters start to use them. So, the purpose of formulation of scenarios is to estimate reduction in emission based on potential shift from private and existing low occupancy public vehicles to high occupancy bus, which is efficiently operated along the routes proposed by the KSUTP. For the comparison of resulting emissions from different scenarios, analysis was done for only the vehicular flows along the selected BRTS routes.

For formulating scenarios, it is proposed to have improved public transport system with the BRTS along the BRTS routes, with the following features:

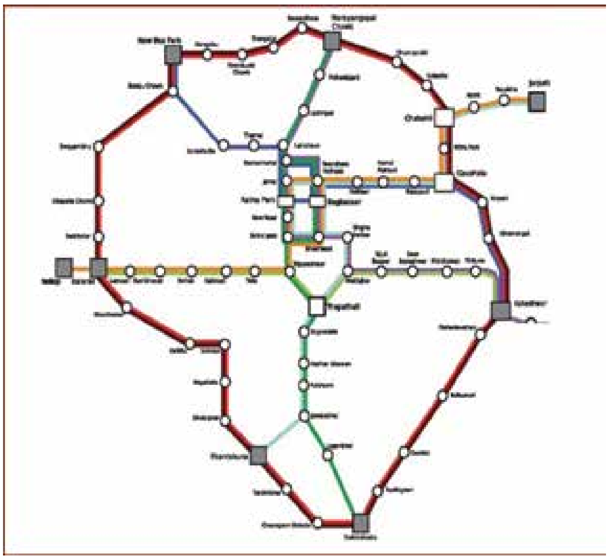
- High occupancy, mass transit service along primary routes as proposed by KSUTP.
- Minibuses, microbuses, tempos in secondary routes, articulated with primary routes.
- Average occupancy: 50

The first scenario, where 25% from private mode are shifting to bus, results in the reduction of emission by 36% in the BRTS routes and 10% in overall emission of base scenario. For the second scenario, the results are 73% and 25% respectively. This clearly indicates that the more the use of public transport, the more is the reduction in GHG emissions. So, more commuters are to be attracted in the use of mass transit modes, shifting

Table 3: Mode Shift Analysis

SN	Scenario	Annual Emission (CO_2e – ton)	Difference with Base Scenario (BRTS Routes)	% Reduction w.r.t Base Scenario: BRTS Routes / Overall
1	Base Scenario	62477.0		
2	Scenario 1 (25% shift)	41053.7	21423.3	36% / 10%
3	Scenario 2 (100% shift)	16973.2	43228.6	73% / 25%

Figure 2: Primary public transport network in Kathmandu Valley (KSUTP Project)



away from the use of private vehicles. To achieve better reductions, the routes are to be expanded to other areas as well so that the effects on overall GHG emissions can significantly be minimized.

Other Strategies to Reduce Emission

Apart from increasing public transport use, the following measures can be promoted to reduce further GHG emissions:

- Encouragement of non-motorized modes;
- Individual awareness of the use of public transport and non-motorized modes;
- Improving vehicle emission standards;
- Proper traffic management and road conditions;
- Promoting transit-oriented city development;
- Alternative energy sources like renewable energy and electric vehicles so as to minimize the use of fossil fuel.

Methods

- Background study of current transport system of Kathmandu Valley;
- Literature review and case studies;
- Data collection: primary data (household survey and roadside interviews) and secondary data;
- Use of Urban Transport Model System (UTMS) to estimate travel pattern in the city:
- Estimate CO_2 and CO_2e emissions for base scenario and formulate scenarios based on potential modal shift from private to public modes;
- Conclusions and recommendations on promoting urban transport system with mass transit to minimize the effects of climate change.

Recommendations

One of the major steps in reducing emission is improving the quality and level of service of bus-based public transport. It all starts from policy level. Policies should be developed in such a way that they promote more investment in mass transit public transport system so that more of such systems could be in operation. Vehicles with high occupancy should be given priority over those with low occupancy. This will help to carry more passengers and also help to reduce road congestion. Planning of cities, their activities and road networks should be made friendly to public transport. Accessibility to public transport has an important role to play in determining its ridership. The routes and location of the stops and their coverage determine this.

Referring to the Kathmandu Valley, the use of private vehicles (especially motorcycles) is expected to rise as they are becoming more affordable to the people. As a result, more and more people, including middle and low income group commuters, are shifting towards the use of the motorcycle. The continuation of this trend could have a negative impact on the share of the public transport. So, taking this issue into consideration, some policies that make public transport more attractive as compared to private modes can be formulated like vehicle ownership cost, registration charge, vehicle tax, congestion pricing, etc. These strategies could help to minimize unnecessary use of private vehicles and promote the use of public transportation. No matter which strategy is used, there is always need for proper planning and appropriate public relation tactics for it to be successful.

Future Research

- **Advancement in UTMS**
  In the context of Nepal, application of model to study transport system has not been introduced. Models could help to study area at macro level and provide useful information for transport planning. Transport model used in this research is in preliminary form. It could be further improved if more data could be made available, especially in the formation of Origin Destination Matrix and Route assignment. For OD Matrix, there is need for comprehensive database of all workplaces and educational institutions, which will include all details regarding that attraction factor. For route assignment of private vehicles, the Volume Equilibrium method could be employed if detailed data on traffic volume is available.
- **Research on vehicular emission**s
  Vehicular emission data used in this research are based on interviews and standards adopted from other countries. For accurate prediction of emission, more detailed study is required on vehicular fuel efficiency and resulting emission, depending upon type of vehicle, its age, driving conditions and other factors.
- **Freight transportation**
  Movement of goods also contributes to the overall transport system, which could be a topic for further research.

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AUGMENTING BLUE LAND USE: AN ADAPTATION APPROACH IN TARAI TOWNS

Ajay Chandra Lal[2], Narendra Man Amatya[2], Neeran Adhikari[2]

Executive Summary

The Terai towns of Nepal, situated along the southern border of Nepal, stretching from Kakadvitta in the east and Mahendranagar in the west, experience extreme temperature well above 40°c every year from March to August. The past trend of temperature analysed for Birgunj, Biratnagar and Janakpur indicates that it is further increasing, though at slower pace, than in the Himalayas. Even a nominal change in temperature will, however, affect the already stressed life in Terai cities. The annual average maximum temperature of Janakpur, the pond city, is increasing at a very slow pace of 0.001°c than that of Biratnagar (0.019°c) and Birgunj (0.007°c) simply because Janakpur has numerous ponds. The socioeconomic conditions in Terai towns show that only a marginal population can afford to adapt to the situation. Most of the Terai towns have, however, numerous ponds within the urban fabric that have lost their relevance in course of transformation agrarian society into urban society.

The research indicated that urban blue land uses (ponds) have significant cooling effects on their surroundings. These effects can not only provide comfort to the people but delay the impact of CC on the cities. The national documents, NAPA and LAPA, do not include specific interventions in urban areas to adapt to climate change impacts. Municipal policies and bylaws at local level are silent about the issues of climate change. Municipalities needs to address the issue of climate change and are trying to mainstream the climate change adaptation policies and strategies. The outcome of the research categorically points out that people living within the vicinity of 25m or 50m from the pond experience 2°c to 1°c lower temperature that those living in other areas. This has huge implications for energy consumption and level of comfort to the population. The national and local governments should adopt the policy of conservation and development of ponds and its surrounding areas from the CCA perspective. In the long run, the concept of Green Plot Ration needs to be incorporated in building byelaws. Proper setback should be provided in case of any construction adjoining the pond.

Context and Importance

Owing to climate change, the city has started to experience aggravated heat waves and extended droughts during summer each year (Bhandary, 2010). Delayed flights and road accidents in the winter due to fog are common features in the region. Nearly 100 people died in southern Nepal due to cold last fortnight (*The Asian*, 14 Jan 2013). Terai towns suffer from chronic water-logging problem caused by inadequate capacity of drainage channels during monsoon and from heat and cold waves during summer and winter respectively. The local government with authority and responsibility of planning and development within its jurisdiction has not even acknowledged climate change in its planning framework (Lal, 2011).

Unplanned urbanization, coupled with climate change, has resulted in depletion in groundwater table, increase in water-borne diseases, frequent flooding of urban streets and decreased agricultural produce in and around the city. Besides green infrastructure, urban blue land use has evolved as a tool to nullify the impact of climate change (Cottus, *et al*., 2012), In this context, augmentation of blue land uses, especially the ponds in the city, can enhance the city resilience against climate change as the conservation of ponds and greening their bank can mitigate the climate change, recharge the depleting groundwater (adaptation to CC), increase the flood water retaining capacity, agricultural activity and fish farming (adapt CC impact)

[2] Department of Architecture and Urban Planning, Institute of Engineering, TRIBHUVAN UNIVERSITY

and recreational activities. The ponds surrounded by orchards in the outskirts of the city could provide organized swimming and chilling services during the scorching summer. Above all, the water in the ponds and green land uses around the banks can further lower the city temperature setting an excellent example of climate change adaptation.

Research Findings

The green landscape could significantly ameliorate the rising temperatures associated with climate change and urban heat island effects, resulting in an increase in human thermal comfort and quality of life and reduced energy bills. An adaptation strategy to cool down towns and cities is believed to lead to the "greening" of urban regions (Bowler, *et al*., 2010). The cooling impact of vegetation inside urban parks is at the rate of 1°c on average in comparison to non-green regions (Coutts, *et al*., 2012). The green plot ratio (GnPR) is currently in use in many cities to control maximum allowable built-up floor area in a building development as climate change adaptation strategy (Wong, *et al*., 2011).

Water bodies are supposed to assist in cooling down the air around them via evaporation and convection (Oke, 1992). Blue body can positively influence the microclimate of the surroundings in a city fabric in hot summer days due to natural cooling coming from evaporation. The blue land use works as a heat sink. Water bodies are the best radiation absorbers, but, on the other hand, they provide very small thermal response (Manteghi, *et al*., 2015). Enriched evaporation is capable of lowering the air temperature and hence mitigates the process of UHI and raises inhabitants` thermal comfort. Arisen evaporation may be reached via increasing the vegetation or the amount of the surface water.

Similarly Volker, *et al*., 2013 carried out literature-based research "Evidence for the Temperature Mitigation Capacity of Urban Blue Space". ΔT, which is the differences in °c between urban blue and non-blue urban areas: ΔT=Turban – Tblue, was calculated. The ΔT was usually posi¬tive, indicating that the urban blue areas were relatively cool during the day around the highest ambient temperatures of the city and negative, indicating that urban blue areas were relatively warm during the night. The ΔT for each study ranged from 0.4°c (minimum) to 5.6°c (maximum). Calculating the median ΔT for all studies (n=27), a cooling effect of 2.5°c was found.

A similar study in Janakpur municipality showed that the temperature difference near pond and away from pond recorded 2.4°c in ward no. 5, which has two ponds in close vicinity. The average difference in temperature is about 2°c. (Table1). Furthermore, the key informant survey and HH survey in three wards confirmed the outcome of the study.

The key informant interview stressed that neither the national nor the local government is sensitive towards pond conservation as the local leadership along with local people could not relate their changed way of living. The ponds are discarded, polluted and encroached by every section of society. Nindyani (2012), interestingly illustrates that the wider river width did not result in a significantly greater cooling effect, which indicates that well distributed ponds can have better cooling impacts, as evident in the case of Janakpur.

Methods

Qualitative and quantitative techniques were used for study in consonant with experimental, as well as pragmatic paradigm. Three wards in the municipality were selected to represent the core, inner fringe and fringe areas of the municipality. Each ward was further divided into three sub-clusters defined by 25m buffer, 50m buffer and beyond. The experiment was carried out for three days in the last week of April when the temperature is generally high. Simultaneously, the temperatures were recorded in 3 sub clusters using synchronized watch and air temperature thermometer. Similarly, key informant survey, HH survey and focus

Table 1: Temperature Difference near and away from pond

Date	Temperature Difference Ward No 5		Temperature Difference Ward No 6		Temperature Difference Ward No 8	
	35m away from the pond	75m Away from the pond	35m away from the pond	75m Away from the pond	35m away from the pond	75m Away from the pond
27-Apr	0.5	1.8	0.2	2.1	0.5	1.5
28-Apr	0.6	2	0.5	1.8	0	1.4
29-Apr	0.6	2.4	0.4	2.2	0.5	2.2

group discussion were carried out to understand their views, experiences and perception on impact of ponds on rising temperatures.

Temperatures data from DHM were analysed using linear regression. A time series analysis was done to understand the past rainfall pattern to help future projections and planning using the past and present data. Among many components of time series, the secular trend method was used to comprehend the general tendency of the time series data to increase or decrease or stagnation during a long period of time.

For future projection, Statistical Downscaling Model (SDSM) 4.2 was used. SDSM Version 4.2 (Wilby 2007) was supported by the Environment Agency of England and Wales as part of the Thames Estuary 2100 project in 2007. SDSM 4.2 (Statistical DownScaling Model) facilitates the rapid development of multiple, low cost, single-site scenarios of daily surface weather variables under present and future climate forcing. Additionally, the software performs ancillary tasks of data quality control and transformation, predictor variable pre-screening, automatic model calibration, basic diagnostic testing, statistical analyses and graphing of climate data.

Recommendations

This literature suggests that wind speed is one of the important aspects for the cooling effects of water bodies and, therefore, the street with east–west direction can take the cooling effects of the ponds well into the city fabric. Other findings obtained from the study showed that the surrounding area near water bodies seems to affect the performance of water bodies in cooling the environment. The measurement result is enhanced if ponds are fitted with fountains and if trees cover the surrounding area and green land as fountains bring cooler water to the surface, increasing the cooling process pace of the air just above the water bodies. Nindyani (2012), interestingly, illustrates that wider river width does not result in a significantly greater cooling effect. The study of ponds in Janakpur, in concurrence with various previous research works on the impact of water bodies on cooling the city fabric, leads to the conclusions that:

- Blue land uses considerably contribute to the cooling effect performance in the environment.
- The surrounding areas like green space or facilities like fountains in water bodies further enhance the cooling effect performance of water bodies.
- The wind increases the cooling effect performance of the blue land uses.
- Wider or bigger water body does not significantly increase the water-cooling performance in the surrounding area in terms of distance.
- Uniformly distributed ponds/water channels with fountains significantly increase the cooling effect rather than big lakes in the city.
- Open spaces and wider streets radiating from the blue body considerably increase the depth of cooling effects of blue land uses.
- Vegetation or solid materials (asphalt/pavements) in the surrounding areas affect the cooling effect performance of water bodies.

The conclusion illustrates that the study has implications for urban planning and urban management. Janakpur, the city of ponds, can set an example of climate change adaption through conservation of urban ponds as the total blue land uses is about 4% of the total area. The ponds are well distributed within the city. The study makes the following recommendations:

- The national climate change policy needs to include creation of water bodies in the city fabric in Terai towns, which will have multiple impacts, besides cooling the temperature. It will help the city recharge the groundwater table, which is depleting as a consequence of climate change. Furthermore, it will hold extreme precipitations and provide a cushion for flood fighting. Besides, it will provide recreational facilities for city dwellers.
- The national and local policies on climate change should provide incentives for conservation and development of ponds from the climate change perspective.
- Local-level awareness campaigns on the need of conservation and creation of new ponds should be mainstreamed in the local development planning.
- Municipal byelaws need to be reviewed and updated to incorporate new dimensions like green plot ratio (GnPR) and sufficient setback from ponds.
- The national and local governments should work together to control encroachment, reduce pollution and restore the glory of the ponds.
- Local government, in close consultation with stakeholders, needs to prepare and implement a conservation and development plan for each pond of the city.
- Awareness campaigns should be launched illustrating the benefits of ponds and their importance in adapting to climate change.

- Women need to be mobilized the most in the case of Terai towns.
- Community participation should be taken as the centre for pond conservation.
- A corporate social responsibility fund could be mobilized for a model conservation plan to demonstrate to the people.

Future Research

The study outcomes need further conclusive research to support it so that it can be implemented at local and national level. Based on this work, in order to assess urban environments and urban heat islands, climate changes in urban area need to be studied, using computer simulation models and, thereby, developing general guidelines for an urban development model based on the potential benefits of water bodies. The following areas were identified for further research:

- To enlarge the scope of this work, using a computer simulation model and linking it with urban design and climate;
- Round-the-year temperature measurements at different distances from water across greater verities of the water body can further strengthen the outcomes. Further research could outline the relationship between the depth of water in the pond/water body and its cooling effects.

Conclusion

Evaporative cooling from water bodies is suitable for areas with high air temperature and low air humidity. In a high air humidity climate, evaporative cooling might be less applicable if it is not supported by increased air flow. The benefits of such a climate model are useful in the urban planning of extreme hot and humid climates.

Based on past and future temperature trend analysis and temperature records at different distances from ponds in Janakpur municipality, some empirical relationships related to water evaporation and its cooling effects can be outlined. Water evaporation depends on several factors, such as air humidity, air and water temperature, surface area of water, velocity of wind over water, and the amount of solar radiation exposure. Water bodies absorb heat from their surroundings when they evaporate and produce a cooling effect. In the process, they act as a temperature sink and adapt to the increasing heat due to climate change and other processes. After absorbing radiation, water molecules evaporate and leave the surface of the water bodies. The literature, field measurements and experiences of key informants indicated that the cooling effects seem to depend on temperature extremes. The wind increases the amount of evaporation as it carries released vapours from water bodies to reduce humidity. The occurrence of wind is caused by differences in air pressure, sending air to the lower pressure area. Increasing the wind speed increases the cooling effects from water bodies, cooling the environment for a longer distance.

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Nepal Academy of Science and Technology
GPO Box: 3323, Khumaltar, Lalitpur, Nepal
Tel: +977-1-5547714 / 5547715
Fax: +977-1-5547713
E-mail: science@nast.gov.np / ncckmc@nast.gov.np
Website: www.nast.gov.np / www.ncckmcnast.org.np
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